

Appropriate Technology, Food Security and Nutrition in Humla, Nepal

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Abstract

Hunger is the most extreme effect of poverty and arises in circumstances where individuals or families cannot meet their most basic need for food. This is more commonly and broadly known as food insecurity. A lack of food and inadequate nutrition will result in poor health, reduced ability to work, impaired mental development and further entrenches the poverty cycle.

This thesis presents a research project undertaken to improve food security in Humla, a remote, impoverished mountain district of Nepal, using appropriate technology. The term “appropriate” refers to technologies that suit the local context, i.e. they can be built, maintained and operated with local materials, resources, expertise and within organisational structures. Long cold winters and inaccessibility mean that Humla has a significant imbalance in food availability and diversity between the summer and winter season, leading to significant food shortages over winter and prominent nutritional deficiencies such as iron and vitamin A. In similar locations, increased food production and preservation has been achieved using appropriate technologies such as solar greenhouses and dryers. However, a systematic approach, where these technologies are used in a complementary way to supply the shortfall in food and address nutritional deficiencies, has not been attempted.

The aim of this research is to investigate the potential for appropriate greenhouses and solar dryers to increase food availability and diversity, and improve intakes for prominent nutritional deficiencies in Humla. The aim is also to develop a transferable method that could be applied in other areas. This method involves simulation using TRNSYS (Type 56) software package and field measurements as an alternative to a pilot-based program to reduce time and resources required to arrive at an appropriate solution.

This research focuses mainly on the performance and cost aspects of the greenhouse and solar dryer designs over the winter season from January to March, the most severe hunger period during the year, and how they relate to crop production. Results were measured against nutritional criteria, performance criteria, “appropriateness” criteria and affordability.

Nutritional criteria were established on a household basis. A quantitative analysis of local food intake based on surveys and a literature review showed the local diet over the winter period is seriously lacking in vitamins and minerals, particularly vitamin A and vitamin C for both of which 0% of the recommended nutritional intakes (RNI) were being met. A lack of bulk food was also indicated by low protein (76.7% RNI) and energy levels (60% RNI). Zinc levels were also low at only 51.7% RNI.

A selection of potential local crops were chosen based on nutrient content, availability and their suitability to be grown or dried in conjunction with each technology. Linear programming was then used to determine the best combination of crops to be grown in the greenhouse or dried in the solar dryer to address nutritional criteria, based on yields, nutrient content and constraints such as labour and palatability.

Both the greenhouse and solar dryer designs were selected from generic, appropriate designs already widely used in other mountain areas. The greenhouse was a walled design with an effective growing area of 25 m². The solar dryer was a wooden box design with a height, width and depth of approximately 0.6 m and an overall tray area was 0.42 m². Both technologies satisfied appropriateness criteria in that they could be constructed and operated with local materials, expertise and resources. Initially the solar dryer was found to satisfy the affordability criteria while the greenhouse did not.

The solar dryer narrowly satisfied the performance criteria, which specified that crops should be dried to safe storage moisture content before spoiling and faster than that of sun drying. Drying times varied between 1 – 5 days, depending on ambient conditions and thickness of samples, with thinner samples found to have a faster drying rate per volume of crop (1.5 kg/day compared to 0.9 kg/day). The average dryer air temperatures varied between 30-40°C, which is lower than the recommended 50-60°C for agricultural crops. However, it was also found that local crops suitable for drying did not contribute significantly to improving nutrition. For the greenhouse, growing temperatures were outside the required range and did not

satisfy performance criteria. Daytime maximum and night-time minimum temperatures were 40°C and 2°C respectively, which were outside the recommended range of 10 - 32°C. However crops could still be produced in sufficient amounts to improve food availability and address some nutritional deficiencies stated in the nutrition criteria. Both cauliflower and spinach were grown successfully over the winter periods with yields of 2.16 and 1.37 kg/m²/month respectively. Nutrient requirements were met for vitamin A (128% RNI) and vitamin C (184% RNI), mostly met for protein (93% RNI) and iron (95% RNI). The results for zinc and energy did not show much improvement at 62% and 63% RNI respectively.

Further investigation of design modifications with the validated simulation model showed that reducing the wall thickness, removing insulation from doors and vents and increasing infiltration would not substantially affect performance. The latter result is significant because increased infiltration is linked to inferior construction, so unskilled labour could be employed to construct the greenhouse and not be detrimental for growing conditions for crops. Overall, with all the above modifications, the effective cost of the greenhouse could be reduced to \$US450, which satisfies the affordability criteria.

Although the solar dryer satisfied the affordability and appropriateness criteria, its poor performance and minimal contribution to improving nutrition mean that this design is not considered appropriate for improving nutrition in Humla. The greenhouse performed sufficiently well to produce enough crops to potentially address some nutritional intakes. Although the initial cost was high, it is thought that modifications could be made to reduce this and therefore this design is considered to be appropriate for use in Humla.

Declaration

This is to certify that:

*the thesis comprises only my original work towards the PhD,
due acknowledgement has been made in the text to all other material used,
the thesis is less than 100,000 words in length, exclusive of tables, maps,
bibliographies and appendices.*

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Abbreviations

ACF	- Action Contre le Faim
AEPC	- Alternative Energy Promotion Centre
AIT	- Asian Institute of Technology
CPA	- Comprehensive Peace Accord
db	- Dry basis (moisture content)
FAO	- Food and Agriculture Organisation
FFW	- Food For Work
GDP	- Gross Domestic Product
GERES	- Groupe Energies Renouvelables Environnement et Solidarités (an international NGO set up in 1977 in France aiming at supporting local organisations to implement renewable energy, environment and income generation activities).
HARS	- High Altitude Research Station.
HDI	- Human Development index
INGO	- International Non-Governmental Organisation
MAR	- Mean Nutrient Adequacy ratio
MOA	- Ministry of Agriculture (Nepal)
NAR	- Nutrient Adequacy Ratio
NCP	- Nepal Communist Party
NFC	- Nepal Food Corporation
NGO	- Non-Governmental Organisation
NPR	- Nepali Rupee
OR	- Operations Research
PPP	- Purchasing Power Parity
RECAST	- Research Centre for Applied Science and Technology
RIDS	- Rural Integrated Development Services (Nepal)
RNI	- Recommended Nutrient Intakes.
SDCP	- Sustainable Development Community Program
SE	- Systems Engineering
SIDA	- Swedish International Development Agency
SNV	- Stichting Nederlandse Vrijwilligers (Netherlands Development Agency)
TRNSYS	- Transient System Simulation Tool
UN	- United Nations
USD	- United States Dollar
VDC	- Village Development Committee

wb	- Wet basis (moisture content)
WEC	- World Energy Council
WECS	- Water and Energy Commission Secretariat
WFP	- World Food Program
WHO	- World Health Organisation.

Chapter 1

Introduction

1 Introduction

Extreme poverty is, and always has been, a serious issue for the global community. Hunger is the most extreme effect of poverty and arises in circumstances where individuals or families cannot afford to meet their most basic need for food. This is more commonly known as food insecurity. In 2001-2002, the Food and Agriculture Organisation (FAO) of the United Nations (UN) estimated that 852 million people were undernourished worldwide, while more than three billion people were deficient in essential micronutrients (FAO 2004). For individuals, lack of food and inadequate nutrition result in impaired growth, immune function and cognitive development, along with a greater risk of premature mortality (Spallholz, Boylan & Driskell 1999). These accumulated affects can reduce labour productivity (Strauss & Thomas 1998), which limits the earning potential of households and communities and further entrenches poverty. Hunger and poverty together also increase the possibility of conflict (Goodhand 2001).

The gravity of this situation is reflected by the fact that both the UN and the FAO have set targets to significantly reduce the number of people who are undernourished or suffering from hunger by 2015¹ (FAO 1996a; UN 2007b). Since the targets were set in 2000 and 1996, respectively, some reduction has been achieved, however, the proportion varies between global regions and sometimes within countries themselves. Overall, the current rate of progress will not be enough to meet the targets in the given time period (FAO/ WFP/ IFAD 2012; UN 2012). In response to this, the FAO is currently promoting a “twin track” approach, which emphasises that direct action against hunger with a focus on agricultural and rural development would be effective in providing the most vulnerable and food insecure people with new livelihood possibilities and hope for a better life (Skoet & Stamoulis 2006).

Nepal is the poorest country in South Asia, with 38% of the population living below the poverty line (UN 2007a). The country is characterised by low levels of

¹ The UN Millennium Development Goals aim to halve, between 1990 and 2015, the *proportion* of people who suffer from hunger, while the FAO World Food Summit Target aims to halve the *number* of undernourished people by 2015 based on the average of the period 1990 – 1992. This amounts to slightly different targets with the FAO/WFS target being the more ambitious of the two.

development and high dependence on subsistence agriculture and imported goods. The combination of low agricultural productivity, land constraints, natural hazards and high population growth causes short and long term food insecurity, particularly in rural areas. According to a recent FAO survey, 42 out of the 75 districts in Nepal were considered to be in food deficit (Fang et al. 2007), where the amount of food available does not meet the needs of the population. The most recent Nepal Micronutrient Status Survey (UNICEF 1998) reported that 90% of Nepalese children are suffering from one or another form of malnutrition. Not only does the higher concentration of malnutrition and hunger affect the quality of life in these areas, it also fuels urban poverty by immigration of rural people to cities (Skoet & Stamoulis 2006).

Humla is a remote rural district in the northwestern corner of Nepal, high in the Himalayas. In the past it was part of one of Nepal's wealthiest regions due to its location on an ancient salt trade route. The demise of trade due to outside influences and lack of development, however, now mean it is one of Nepal's poorest districts. Long, harsh winters and a short growing season make it subject to severe food insecurity. Agriculture is difficult due to steep slopes and infertile soil. In addition to this, mountainous terrain and damage to infrastructure from the Maoist rebellion and political conflict hinders accessibility. Food produced locally is not sufficient to meet the demand and it is prohibitively expensive, or sometimes impossible, to import adequate food to the area. There is a general lack of food overall, but also a significant imbalance between food availability and diversity in the winter and summer seasons, with the growing season for fresh vegetables limited to three to four months per year. As a result, the region has high levels of chronic malnutrition and micronutrient deficiencies (Emeriau 2006).

A number of national and international organisations are active in providing food and nutrition aid to Humla. Bulk food supplies, such as rice and fortified flour, are being imported by both the Nepal Food Corporation (NFC) and the World Food Program (WFP). To address micronutrient deficiencies, vitamin and mineral supplements are distributed in Humla as part of the national vitamin A and iron supplementation programs. Overall, all of these food aid programs provide temporary food and nutrition relief rather than long-term improvements in food availability and do not contribute to agricultural development. The centralised nature of these programs is not well suited to Humla due to extreme topography

and lack of transport infrastructure. High transportation costs and external funding constraints reduce the amount of food that can be distributed in remote rural areas or prevent it from being distributed at all (Dingle 2011; Fang et al. 2007).

Although very little data is available on the nutritional status of the Humla population, that which is available indicates prominent nutritional deficiencies. According to a recent nutritional evaluation by Action Contre le Faim² (ACF) (Fournier 2007), the prevalence of global chronic malnutrition, an indication of long term food shortages, in children under five was found to be 68.5% in Humla. In addition to this, both the anaemia and night-blindness prevalence of 24.7% and 20.8% respectively in post-partum women were sufficiently high to be considered a public health problem. Anaemia and night-blindness are indicators of deficiencies in iron and vitamin A respectively. These figures correlate with low distribution rates of vitamin A and iron supplements (Emeriau 2006; MOHP 2007), which further supports the argument that an alternative to centralised programs is required in Humla.

ACF is engaged in agricultural programs in Humla focusing on irrigation, vegetable production, improved seeds and methods of fertilisation and management of diseases (Fournier 2007). This is a common approach to increase yields and address food insecurity locally and is also being used by Oxfam in the Dadeldhura and Daleikh hill districts of Nepal (Kilpatrick 2011). It does not, however, extend the growing season or address the issues of fresh vegetables to alleviate micronutrient deficiencies in the winter season.

In some mountain regions in Nepal, India, China and Pakistan, solar greenhouses and dryers have been used to grow and preserve food crops respectively. The designs used adhere to the principles of “appropriate technology” in that they can be built, maintained and operated in the geographical and cultural context for which they are intended. They were developed over a ten-year period through community based pilot programs and results show that local food availability has been significantly improved, particularly in the winter. However, a systematic

² “Action Contre Le Faim”: French for “Action Against Hunger”

process involving crop selection and using the technologies in a complementary way to address nutrition has not been attempted.

In Humla, a small number of solar dryers and greenhouse structures of varying complexity exist. The more elaborate structures have been built by local and international non-government organisations. Recent research shows that more needs to be done to improve the performance and management of these technologies (Fuller, Aye & Zahnd 2007; Fuller et al. 2009). Possibly influenced by the larger greenhouse structures, local merchants have installed their own basic polyethylene tunnel structures, which are useful for frost protection and a small extension of the growing season, but do not allow year round cultivation. This shows some acceptance of the technologies, but the results from a recent anthropological study indicate that the subsistence population are risk averse to using their minimal land or labour time for agricultural endeavours that do not have known outcomes (Sanders 2010). This means more research and practical demonstrations are required to determine the effectiveness of these technologies. Although the greenhouse and solar dryers used successfully in other areas would address the seasonal food imbalance, they may not be acceptable to local people whose resources are already stretched.

The aim of this research is to investigate the potential for appropriate greenhouses and solar dryers to increase food availability and diversity and address prominent nutritional deficiencies in Humla, and to develop a transferable method that could be applied in other areas. This method involves simulation as an alternative to a pilot-based program to reduce time and resources required to arrive at an appropriate solution. This research focuses mainly on the performance and cost aspects of the greenhouse and solar dryer designs over winter and how they relate to crop production. Although a nutritional analysis is done to quantify deficiencies, it is not intended as a comprehensive nutritional survey. In addition to this, although general principles of crop growth are applied to determine outcomes, in-depth physiological models are not applied because they are outside the scope of this research.

Before setting out the research method, the thesis commences with an introduction to Humla and existing solar technologies appropriate for other mountain areas. Chapter 2 begins with an explanation of the concepts of food

security, nutrition and poverty, followed by an overview of the geography and demography of Humla and specific aspects related to the food situation. This information is used to define the food problem in Humla and determine requirements and constraints for potential solutions. Chapter 3 presents an overview of greenhouses and solar dryers used in other mountain areas that could address these requirements. It begins with an explanation of the concept of appropriate technology, followed by a discussion of existing solar technologies in Humla and local reactions to those technologies. This gives an indication of the state of technological development in the area as well as an indication of the acceptance of new methods. Following this, greenhouse and solar dryer technologies used successfully in other similar geographical areas are presented. Where possible, the designs and implementation strategies are outlined and discussed.

Chapter 4 outlines the research design, beginning by setting out the research question. The characteristics of the socio-technical research problem are discussed and the nature of the problem is then defined. Following this, the choice of a hard systems approach with consideration of values and cultural aspects/criteria of the problem as requirements and constraints, specifically a systems engineering methodology, is justified. The implications of this choice of methodology on the scope of the research are then discussed. Following this, the specific criteria and methods that will be employed within this methodological framework, and the justification of each method, are outlined. These include the intake method for measuring nutrition, linear programming for crop selection and a combination of experimentation and simulation for technological design and improvement.

Chapter 5 is concerned with quantifying nutritional deficiencies and the potential contribution of additional produce. The nutritional requirements and current nutritional status of a typical Humla family were used to determine the criteria or "nutritional gap" that production from the greenhouse and solar dryer would be required to meet. Potential crops for each technology were chosen based on local availability, required growing conditions and their nutritional content. Following this, a multi-variate analysis with linear programming was used to estimate their optimal distribution in the greenhouse, the most suitable greenhouse size and the amount of fresh food that should be harvested for drying in the solar dryer. The

findings from this analysis were used to inform decisions for the experimentation process.

Chapters 6 and 7 outline the design selection, construction, experimental method, and results of both the greenhouse and solar drying testing in Humla respectively. The designs are selected according to “appropriateness” criteria based on local constraints and requirements. Successful construction and operation satisfy these criteria. Experimental results are then compared to performance and nutritional criteria to determine the viability of each technology.

The results from Chapter 5, 6, and 7 led to the research being focussed on the greenhouse alone, and specifically reducing the cost of the structure to satisfy the “appropriateness” criteria, as the crop production was already sufficient to meet the nutritional criteria, even with conditions that were outside the performance criteria. Chapter 8 outlines the modification of the design via simulation. It includes the development and validation of the model with experimental data, and using the model to test different strategies to reduce the cost of the greenhouse while maintaining performance.

The results presented in Chapters 6, 7 and 8 are discussed in detail in Chapter 9. This discussion is drawn together to set out the implications of the research for the implementation of solar dryers and greenhouses. The limits of the research are also revisited in this chapter and areas for further research suggested. The thesis is brought to a close with the brief presentation of formal conclusions in Chapter 10.

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Chapter 2

Introduction to Food Security and Nutrition in Humla

2 Introduction to Food Security and Nutrition in Humla

Before setting out the research method in Chapter 3, this thesis commences by introducing the research locale and major concepts. The former is particularly important for the development of appropriate technology solutions and will be covered in some detail. Like the thesis, and like most complex development problems, this chapter is necessarily multidisciplinary, drawing upon diverse interlinking subject matter. It also moves between both the general and the specific, introducing terms and concepts, and then situating them in the real world in order to discuss their application to this thesis.

Section 2.1 begins with an explanation of the broad concepts of food security and nutrition and how the lack of these relates to entrenched poverty and disadvantage. The aim is to show the importance of adequate nutrition for development to provide context and justification for this research. Section 2.2 follows with a detailed examination of the locality of Humla, the setting for the research, introducing geography and climate, demography and history, agricultural conditions and accessibility. In Section 2.3, the discussion then draws together the definitions in Section 2.1 and the information presented in Section 2.2 to show how those attributes of Humla pose challenges to food availability and adequate nutrition.

The aim of these sections is to briefly introduce the broader implications of poor nutrition and to define the food and nutrition problem in Humla. This will be used in the formation of the research question in Chapter 4. Section 2.3 concludes with a discussion of the recommendations from past research in Humla and the surrounding region, to determine the requirements for potential solutions for the defined problem.

2.1 Food security, food sovereignty, nutrition and poverty

This section introduces the broader concept of food security, which is necessary not only as criteria against which the food situation in Humla can be measured, but also as a framework within which appropriate solutions should be generated.

It also briefly introduces the alternative concept of food sovereignty, since this is also significant to the situation in Humla.

2.1.1 Food security

Food security as a concept originated only in the mid-1970s, in the discussions of international food problems at a time of global food crisis. The initial focus was on the volume and stability of food supplies, focussing mainly on bulk foods and measured by calorific consumption (UN 1975). In the following decade, the concept of food security evolved to include securing economic access by vulnerable people to available supplies (FAO 1983) and accounting for temporal dynamics of food availability caused by seasonal variation, natural disasters, economic collapse or conflict (World Bank 1986). It wasn't until the mid-1990s that the definition was broadened to incorporate food safety, nutritional balance and food preferences, recognising concerns about food composition, detrimental effects of micro-nutrient deficiencies and social and cultural aspects of food consumption (FAO 1996b).

The Food and Agriculture Organisation (FAO) currently define food security as a situation that exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2001, p. 50). This definition is most commonly used in developing food security programs. It focuses on four key components: availability, access, stability and utilization (FAO 2006, p. 1):

- Availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid).
- Access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet.
- Stability of food supply. To be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity). The concept of stability can therefore refer to both the availability and access dimensions of food security.

- Utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well being where all physiological needs are met. This brings out the importance of non-food inputs in food security.

Overall, this definition of food security implies that food can come from different sources, but for an area to be food secure, a sufficient, steady and diverse supply is required along with complimentary health related factors. The potentially high degree of context specificity shows that the concept of food security is not a goal but an intermediating set of actions that contribute to an active and healthy life.

Food security emphasises the necessity for everyone to have access to and be able to utilise adequate, acceptable food, but it does not say anything about where that food comes from or how it is produced. The more specific concept of food sovereignty was developed in response to this and relates to the right of communities to define their own food systems (Via Campesina 1996). It elicits certain guidelines that take into account the cultural and social, political, geographical and environmental context of the community in order to develop an appropriate plan of action to address the community's particular problems and needs (Nyeleni 2007). Food sovereignty puts ownership of food systems into the hands of the communities themselves. It involves a sustainable, long-term process in which a community can establish its own food systems and produce its own local products without being subject to fluctuating international markets.

While food solutions that aim for food sovereignty entail food security, solutions that aim for food security do not inherently imply food sovereignty. For the purposes of this research, food sovereignty is considered to be a precondition to genuine food security, so when solutions to improve food security are discussed, their applicability for food sovereignty is implied.

2.1.2 Link between poverty and poor nutrition

It is well understood that socio-economic poverty contributes to poor nutrition, since poor families have less access to nutritious food due to a lack of both agricultural and economic resources. However, it has also been suggested that poor nutrition contributes to poverty, and entrenching the poverty cycle. This section aims to show how poor nutrition contributes to capacity deprivation and

subsequent poverty, to justify the focus of this research on the nutritional benefits of increased food production.

The UN definition of poverty includes the statement that it is “a lack of basic capacity to participate in society” (UN statement, June 1998). Poor nutrition reduces a person’s ability to participate in a number of ways. The most obvious of these relate to physical condition. It is well understood that poor nutrition increases susceptibility to disease, ill health and mortality (Field, Johnson & Schley 2002). These weaken the poor by diminishing their physical capacity and their ability to contribute to their households, resulting in lost incomes and reduced productivity. It is acknowledged that poor sanitation, water quality and living conditions also contribute to spread of disease, however better nutrition would lead to better resistance in regions where poor sanitation is apparent.

Less obvious however, is the effect of poor nutrition on educational outcomes. A negative correlation between chronic under-nutrition and academic achievement has been reported in past research (Glewwe, P, Jacoby & King 2001). The most controversial conclusions focus on the causation that poor nutrition in childhood, especially in the first two years of life, would lead to a delay in primary school enrollment, to repeat grades, to have larger negative cognitive development (Gale et al. 2004; Glewwe, Paul & King 2001; Pollitt 1993; Thomas, Grant & Aubuchon-Endsley 2009). The studies by Glewwe, Jacoby and King (2001) and Glewwe, Paul and King (2001) specifically relate to research in developing countries.

These examples show that poor nutrition is not only a result but also a significant contributor in the poverty cycle. At a local level, poor nutrition reduces a household’s capacity to provide for themselves on a day-to-day basis. At the macro level, poor nutrition burdens national budgets, and lost incomes and lower productivity slow down economic development. They suggest that improved nutrition could improve both educational outcomes and productivity, both of which are well understood to be associated with reducing poverty.

2.2 Humla

This section provides an overview of the geography, climate and history of the Humla district, with particular focus on determinants of food availability.

Following this, actual food availability, agricultural conditions and subsequent nutritional status of the population are outlined.

2.2.1 Geography and climate

Humla District is situated in the Mid Western region in the northwest corner of Nepal, bordered by the Tibetan plateau to the north and the Himalayan mountain chain to the south (Figure 1). It is part of the Mountain ecological zone, which has a colder climate, higher altitudes and less land available for cultivation than the Terai (plains) and Hills, the other two main ecological zones. Officially, Humla is considered to be part of the Mid-Western Mountains development region, also known as the Karnali region.



Figure 1 – Map of Nepal, Karnali and Humla showing development regions and ecological zones (UN 2007c).

Geographically, Humla forms part of the remote topographical region known as the Inner Himalayas, which are described by Hagen (1980) as the “real high mountain valleys of Nepal, surrounded on all sides by ice clad giants” (Figure 2). The Humla district lies between elevations of 1624 m to 7768 m above sea level, with over 75% of land above 5000 m in the High Himalaya (Ojha 2009).

Due to its high altitude and location in the rain shadow of the Himalayas, Humla has a cold, dry and sunny alpine climate. In the Karnali region overall, the summer starts from May and the winter starts in October. Rainfall is low compared to other mountain areas in the east and on the southern side of the Himalayas (Zurick & Karan 1999, p. 26). Rain events occur mainly in the monsoon season from July to August, with some in the winter. The onset and recession of the monsoon and distribution of winter rain are quite erratic. Although no specific crop data could be found for Humla, these conditions have been known to cause moisture stress to crops in other districts in the Karnali region (Whiteman 1979).



Figure 2 – The Humla Valley – March 2008 (photo – S Candy)

Figure 3 shows average temperatures, solar radiation and relative humidity as measured by local NGO RIDS Nepal in Simikot, the district administrative centre. Average minimum and maximum temperatures are between -2°C and 15°C in winter (January – March) and between 8°C and 21°C in the warmest months (during parts of the summer and monsoon seasons). This village is located at an altitude of 3000m and has weather conditions indicative of the middle of the Humla district, where this research is being conducted (Figure 4). Figure 3 also

shows the six Nepali seasons and corresponding months. Generally, Nepali months fall in between two months of the Gregorian calendar.

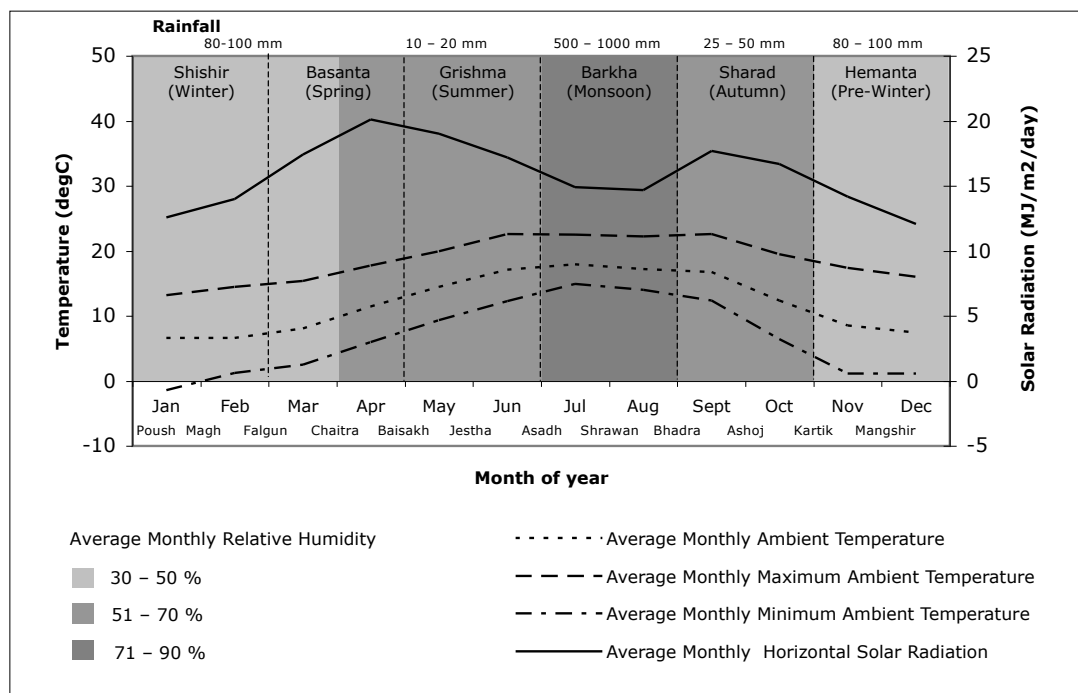


Figure 3 – Average weather conditions in Humla (data collected 2004-2007).

Weather variability is very high in all the dry belts of Nepal. Strong winds, hailstorms, cold weather and drought conditions adversely affect agricultural production. Wind speeds start to increase in March, and reach up to 55 – 65 kilometres per hour in April and May, enough to blow away the flowers and buds of fruit trees (Adhikari 2008). Hailstorms are common and occur at the end of the monsoon, just prior to the main grain harvest season in September and October (Figure 5). These damage ripening crops and significantly reduce yields. Snowfalls were observed during fieldwork in late April (Figure 5) and have been known to occur as late as June (Adhikari 2008).

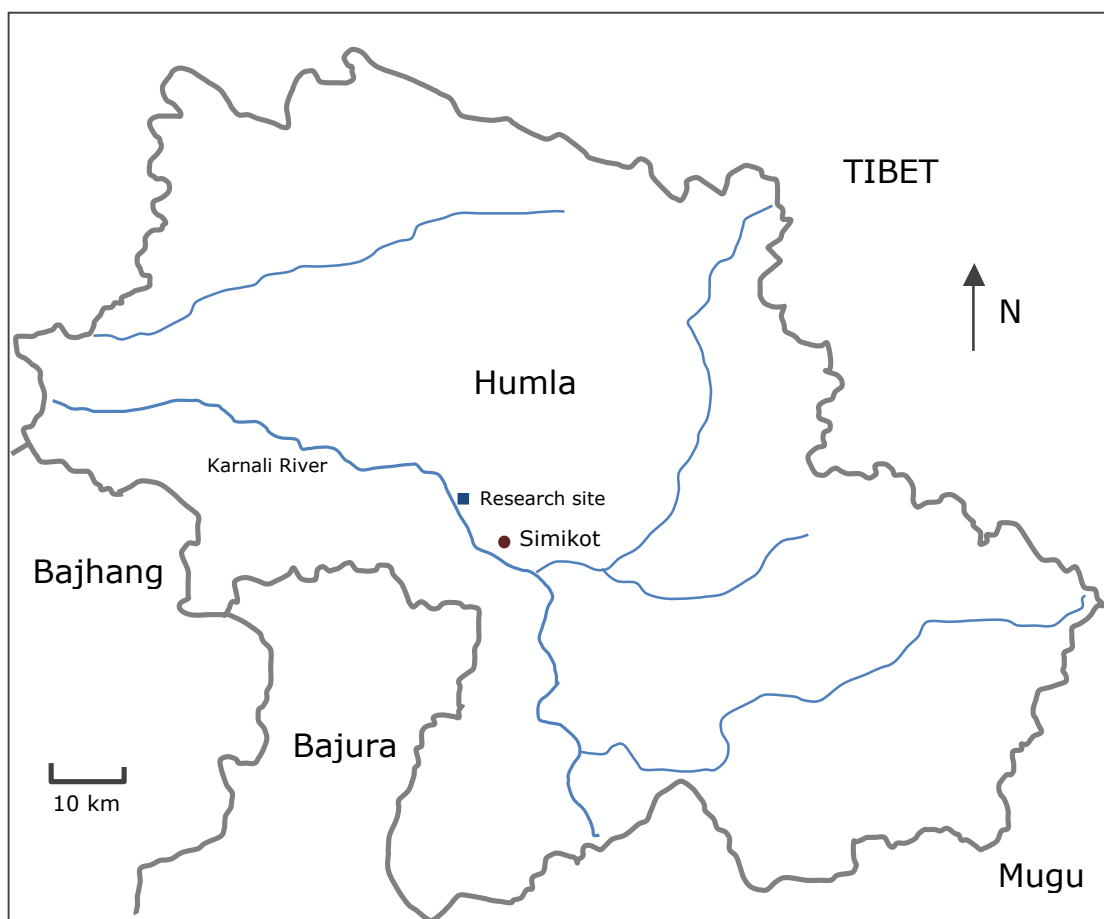


Figure 4 – Map of Humla with location of Simikot and research site.

Nepal, and Humla in particular, is also susceptible to drought. A 2008/2009 winter drought caused almost half the country to match or set new record low monthly rainfall levels. In Humla, the 2009 drought caused a drop in crop yield by more than 30%, resulting in it being categorised as severely deficient in terms of food sufficiency (WFP 2009). Figure 5 shows dry fields following the winter drought.



Figure 5 – Ice on rooftops following a severe hailstorm in September 2009; Snowfall on spring blossoms in April 2008; Dry fields in March 2009 following the winter drought (photos – S Candy).

Whilst little specific data is available, it is clear that Humla has a challenging climate, with extreme weather, cold conditions and steep terrain making agriculture and access difficult. This has ramifications for food availability that will be discussed further in this chapter.

2.2.2 Demography

Like other districts in the Karnali region, Humla is one of the least economically developed in Nepal. According to the Human Development Index (HDI) 2001, which measures development on the basis of parameters such as life expectancy, literacy, and standard of living, Humla ranks 68th out of 75 districts of Nepal (UNDP 2004).

Figure 6 shows an example of a typical village in Humla. As can be seen in this figure, infrastructure is minimal throughout the district. There is little technological development, no electricity or running water and predominance of manual labour. Daily tasks for women include collecting firewood and water for cooking and drinking (Figure 7 - left). Sanitation facilities are minimal with only 18% of the population having access to toilets (ICIMOD, CBS & SNV 2003). Current development programs by local NGO RIDS Nepal over the past decade include the installation of tap-stands and toilets in some villages, but these are still not widespread.



Figure 6 – A typical village in Humla (photo – S Candy).

There are no roads, so villages are connected by trails and tracks with the only means of transport by foot or animal (Figure 7 - middle). This results in long walking times to facilities such as markets, health posts, schools and communication facilities, given the lack of any electronic means outside Simikot. Another local NGO, Nepal Trust, runs a temporary health post program in villages, but resources are limited. As was discussed in the previous section, accessibility to large parts of the district is further hindered by snowfall during winter (Figure 7 - right).



Figure 7 – Woman carrying water from local water source; Goods being transported by animals along narrow tracks; Snowfall in villages (photos – S Candy).

In 2003, Humla District had a population of 40,749 (CBS 2003). Of these, 83% are Chhetri, Thakuri, Brahmin or Dalit (i.e. Hindu) of the Indo-Aryan language group (Figure 8 - left) and 17% are Lama of the Tibeto-Burman language group (CBS 2003) (Figure 8 - right). The research site lies on the northerly border of Hindu ethnicity and caste communities, abutting Lama communities to the north and including some of the most marginal cropland in all of Nepal (Sanders 2010). The annual per capita income in 2004 was estimated as US\$186 (UNDP 2004, p. 156), and there is little or no cash economy (Haddix-McKay et al. 2007). Most income is generated through gathering and selling firewood and from family members migrating seasonally to work in other districts (Leduc, Shrestha & Bhattarai 2008). According to 2006 data, 41.5 % of the population live below the poverty line (CBS 2006).



Figure 8 – Hindu women carrying firewood; Lama woman weaving (photos – S Candy).

The Karnali region and Mid-Western mountains are peculiar in their domination by Hindu caste structures. As mentioned previously, Lama people make up only 17% of the population in Humla, while in other areas with similar altitudes they are dominant (CBS 2003). Lama people share common practices with the Tibetans. Trade is the basis of their livelihood and generally their living conditions are better than their Hindu counterparts (Adhikari 2008). This aspect, along with the fact that their culture does not share the fatalistic tendencies of Nepali Hinduism, makes them more likely to introduce and develop practical technologies to improve the productivity of their land (Bista 1994).

Various reasons have been identified in this section for the total lack of development in the Karnali zone. Mountainous terrain and sparse population density make it costly and difficult to provide electricity, water, communication and transportation facilities. However, other mountain areas in Nepal with similar geographical challenges have comparatively better infrastructure. Mountain districts in the Eastern and Western mountains, such as Mustang, Manang and Solukhumbu, have HDI rankings higher than that of Humla, and also higher than the overall rural and national values (UNDP 2004). Having such a small percentage of Lama people in Humla compared to other mountain areas could contribute to the lower overall living standards in the district and implementation of new technologies. Nepal itself is the poorest country in South Asia, with 38% of the population living below the poverty line (UN 2007a), which indicates that the country itself has little resources for infrastructure. Although the cultural differences between Karnali and other mountain areas are considered a factor in the lack of development, this alone could not be considered the single cause. The following section explores historical and political aspects that are considered significant to development in Humla.

2.2.3 History, Politics and Conflict

In the past, the situation in Humla and the Karnali region was not nearly so impoverished. Similar to other districts along Nepal's northern border, Humla served as a channel for the lucrative salt trade for many centuries (von Furer Haimendorf 1978). Humla traders would purchase Tibetan salt, transport it using sheep and goats (Figure 9) to sell in the landlocked middle ranges of Nepal. Grain and rice would then be purchased and transported back to the mountains to be

sold in Tibet. The trading generated income and brought additional grain into the area to supplement home grown supplies. The travel involved also allowed larger herds to be kept, since animals could graze in the lowlands during the winter when there was insufficient fodder in the mountains.



Figure 9 – Sheep caravan passing through Darapori village in Humla (photos – S Candy).

However, the combined effect of increased border controls due to the Chinese authority over Tibet and improved lowland infrastructure allowing cheap Indian salt imports further into Nepal diminished the trade through Humla. Since the pace of road construction did not match the demise of the trade route, it left the Humla people largely isolated from the rest of the country, with few food imports and insufficient arable land for the size of the population.

The reason for the lack of roads and other infrastructure has been attributed to political factors by some authors. Shah (2001, 2062³ – cited in Adhikari, 2008) argues that Karnali has been discriminated against by the central government since the unification of Nepal in 1769 because they did not surrender as easily as in other states in the Far-West. Lack of political commitment to develop the region continues today. Although per capita development expenditure is relatively high (ICIMOD, CBS & SNV 2003), most of the funds are spent on food subsidies and salaries of external government personnel (Bhattarai & Shahi 2062; Shah

³ Published in 2062 in the Nepali calendar, which is a lunar calendar that is approximately 57 years ahead of the Gregorian calendar. The year 2062 corresponds to 2001 in our regular calendar.

2062; Shahi 2062)⁴. This compounds the problems that already exist due to geography and climate, increasing the social and political exclusion of the Karnali region. This is even more pronounced in Humla since it is one of the most remote and least developed districts in the region.

The more recent Maoist insurgency from 1996 to 2006 further stalled development and possibly set it in reverse through destruction of existing infrastructure (Figure 10 - left), reduced access to healthcare and education, reduced agricultural production (Fang et al. 2007; UNICEF 2006). The functioning of normal economic activities deteriorated after 1996, reducing the ability of the economy to withstand shocks, such as loss of agricultural production due to natural disasters (Fang et al. 2007). Government funds were diverted away from development and aid agencies had to suspend activities due to security concerns (Mayhew, Bindloss & Armington 2006). Humla itself was heavily affected by the Maoist rebellion, particularly in the areas of healthcare and access (Haddix-McKay 2003).

In April 2006, after ten years of conflict and massive popular demonstrations, the King was pushed to re-instate the parliament he dissolved four years previously. This led to the declaration of a ceasefire, a Comprehensive Peace Accord (CPA) and the inclusion of the Maoist party in an interim government. The new parliament reduced the king to a figurehead, ending powers enjoyed by the royal Shah lineage for over 200 years (Mayhew, Bindloss & Armington 2006). In April 2008 elections were held to select representatives to determine the new constitution (Figure 10 - right). One of their first decisions was to declare Nepal a republic and to remove the King as head of state.

⁴ Published in 2062 in the Nepali calendar, which is a lunar calendar that is approximately 57 years ahead of the Gregorian calendar. The year 2062 corresponds to 2001 in our regular calendar.



Figure 10 – Damaged water tap stand in Tulin village; Local people queuing to vote in the 2008 elections (photos – S Candy).

It is unclear yet what the change in the central political system will mean for remote and impoverished regions such as Humla. Shah (2001, 2062⁵ – cited in Adhikari, 2008) argues that leadership rooted in Karnali is essential for development, that there has never been anyone in the central government who is concerned about Karnali. He believes that unless such leadership is developed through a bottom up approach, the prospects for development in Karnali, and Humla, are poor.

It is clear though that the current situation in Humla is unsustainable without some form of assistance. In mountain areas of Mustang and Manang, state subsidised development programs have been successful in reducing poverty (ESAF 2004). These areas however are important for national tourism, so are perhaps more likely to be favoured by the central government. Because of the mismanagement of government food subsidy programs in Humla (see Section 2.2.5), it is also questionable whether the assistance would reach those in need. In other parts of Nepal, short-term migration for employment has been effective in generating additional family income (Lokshin, Bontch-Osmolovski & Glinskaya 2007). Due to the remote location of the Humla District, this would involve travel of around two weeks, so would only be feasible for longer periods of work. It also results in higher work demands on the women and children who are left behind to manage cropland and livestock at home (Sanders 2010), reducing the latter's

⁵ Published in 2062 in the Nepali calendar, which is a lunar calendar that is approximately 57 years ahead of the Gregorian calendar. The year 2062 corresponds to 2001 in our regular calendar.

prospects for education. Wholesale immigration of the entire population would also not necessarily improve food conditions. According to a recent report from the FAO (ESAF 2004), farming families who moved to lower lying areas in search of a better life often end up living on marginal land on the edge of recently cleared forest for which they have no legal ownership. They are only able to produce enough food for around four months of the year and can potentially be evicted by forest officials at any time. All of these aspects support the argument that locally based initiatives are required to address the persistent problems in Humla.

2.2.4 Local Food Availability and Agriculture

Food availability refers to the possibility of feeding oneself either from self-production or importation. Currently, in Humla subsistence cultivation is practiced by most inhabitants using primitive techniques and with the majority of work being done by hand. Only basic irrigation systems exist, these being limited to directing streams towards agricultural fields. The main cereal crops include barley in winter and various types of millet (Figure 11), grown in the winter and summer respectively. Other grain crops include sweet and bitter buckwheat, maize and amaranth. A small amount of rice is grown in low-lying fields close to the Karnali River.

Vegetables such as beans, spinach, black lentils, carrots, pumpkin and cucumber are grown in the warmer months, while other root vegetables such as potatoes and turnips can be grown in the shoulder seasons of spring and autumn and stored for use in the winter months. Apples are grown in some villages and other temperate fruits such as *chuli* (a local fruit similar to an apricot), and *khamu* (plum) also grow wild in the region. The fruit ripens as early as July at lower elevations, but they are often eaten (unripe) as early as March and April due to food shortages after the long winter. Local villagers harvest the wild fruit primarily for their oil-rich seeds, but also eat the flesh. Although more is available than can be consumed at harvest time, none of the fruit is preserved in any way.



Figure 11 – Manual harvest of grain in September 2009; Millet crops (photos – S Candy).

Figure 12 shows the availability of most crops throughout the year, using data from a survey by RIDS Nepal in 2008. It must be noted that this figure is representative of the region and that not all crops are available for all families. The comparative volume of each crop is also not shown.

Overall, agricultural production is low due to lack of arable land, cold conditions lengthening the growing period and extreme weather events, and is insufficient to feed the growing population. The per capita cereal production in Humla in 2006 was just 87 kg, the second lowest in the country and significantly lower than the minimal requirement of 203 kg suggested by the FAO (Fang et al. 2007). Snow cover reduces vegetable production to just 3 - 4 months each year. Most households cannot produce enough food for the year and, on average, only manage to feed family members from their own land for three to five months each year (ESAF 2004; WFP 2009).

Access to imported food is also problematic. As mentioned previously, the population is sparse and there is little or no cash economy, therefore markets are rare. For some communities, the nearest markets are as far as four to five days walking distance (Fang et al. 2007). Due to the lack of roads, food and other goods can only be brought in by plane or carried overland, considerably increasing transport costs. These result in high market prices, which, combined with low purchasing power, render most market goods unaffordable. Adverse

weather at certain times of the year can also prevent importation of goods and access to markets entirely.

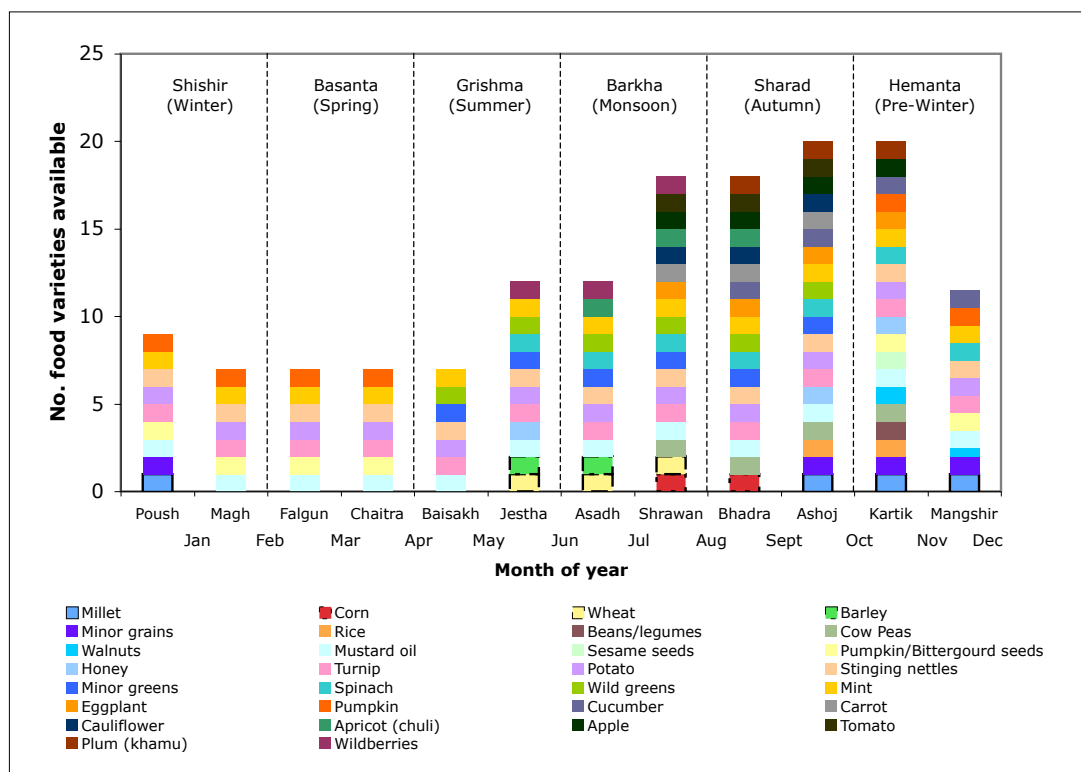


Figure 12 – Availability of crops throughout the year in Humla (data from survey by RIDS Nepal).

As a result of these conditions, food availability is low and there are chronic food shortages in Humla. Significant hunger periods occur prior to the main grain harvests in June and September. Of these two, the late winter – early spring hunger period is more severe due to the fact that no additional vegetables can be grown (Figure 12). There is also a significant imbalance between the food available in the good season and the hunger periods. In July and August, grain is available from the summer harvest and vegetables and fruit can be harvested, so food is plentiful (Figure 12). However with no electricity and little other infrastructure for preserving food, there are few methods available for storing any surplus for the winter.

2.2.5 Food and Nutrition Aid

To address food shortages in food deficit districts such as Humla the government has been subsidising and transporting food through the Nepal Food Corporation

(NFC). Created in 1974, its activities involve purchasing major food items from surplus regions to fill supply gaps in deficit regions. In Humla, the NFC imports rice by air and distributes it from the rice depot in Simikot (Figure 13 - left). According to 2003/2004 figures from the Sales Department of the NFC (cited in (Adhikari 2008), the per capita food aid delivered to Humla was 17.75 kg per year.

The main aim of the NFC's activities was to provide food to remote and food deficit districts to help improve food security in those areas (Sharma 2005). However, a number of factors indicated that this was not being achieved. Distribution was limited due to high transportation costs and reported to be largely benefiting government employees rather than those in need (APROSC 1998; Seddon & Adhikari 2003; Sharma 2005). Since the amount of food distributed in most food deficit areas (38 districts) in 1994 reduced the deficit by less than 4%, it was argued that the NFC's operations in remote areas served more of a political purpose than the improvement of the food security situation (ANZDEC 2002). The NFC underwent a reform process in the late 1990s in order to address their reported inefficacy in addressing food security. However, the results of a recent FAO mission indicate that sufficient food aid is still not reaching some of the poorest mountainous areas such as Humla (Fang et al. 2007).

Other major food programs currently in operation in Humla include the Rural Community Infrastructure Works (RCIW) and the Primary School Feeding program, which are run by the government and supported by the World Food Program (WFP). The RCIW provides seasonal employment to villagers for building sustainable infrastructure. Unskilled labourers are paid family food rations (rice and fortified flour – Figure 13 middle and right) and cash for the work performed. The Primary School Feeding program aims at encouraging enrolment and regular attendance, particularly of girls, by providing regular midday meals at government primary schools (WFP 2011).

From 2002 to 2006, 140,111 metric tonnes of food was distributed from WFP supported programs, most of which went to the Far-West and Mid-Western regions, of which Humla is a part. This equates to an average of about 32 kg of food per beneficiary per year (Adhikari 2008). According to recent media reports,

reduced funding resulting from the confusion following the 2008 global financial crisis has forced cuts in many food assistance projects in Nepal, particularly in the western regions. The scaling back of WFP assistance, including the halt of helicopter and air operations used to fly aid into remote regions, is projected to decrease the number of those receiving food aid from one million to approximately 100,000, suggesting that food security conditions in regions such as Humla will undoubtedly worsen in the near future (Dingle 2011; Jolly 2011)



Figure 13 – NFC rice depot in Simikot; Sacks of WFP donated rice; Fortified flour (photos – S Candy).

In addition to food aid, vitamin and mineral supplements are distributed in Humla as part of the national vitamin A and iron supplementation programs. The Nepal National Vitamin A Program has been in place since 1993 and, as of October 2002, now covers all districts in the country. The aim is to reduce night-blindness and associated problems caused by vitamin A deficiency. During the distribution periods, postpartum mothers receive 200,000 international units (IU), children 6-11 months receive 100,000 IU and children 12-59 months receive 200,000 IU of vitamin A. Children under 6 months are not covered because most children in this age group are breastfed and receive vitamin A through breast milk. Vitamin A distribution is carried out during the months of Baisakh and Kartik in the Nepalese calendar (late spring and late autumn - see Figure 3)(MOHP 2007).

Iron supplementation during pregnancy has been a key health initiative in Nepal since 1980. According to the government policy, all pregnant women are supplied with iron tablets containing 60 mg of elemental iron, free of charge. The iron

tablets are provided to all pregnant women from the beginning of the second trimester of pregnancy and are continued for up to 45 days postpartum (225 days total). As of 2006, the iron supplementation program covered 20 of the 75 districts in Nepal (MOHP 2007). During fieldwork undertaken in 2008, it was established that Humla was one of the districts where tablets were distributed.

Table 1 shows the national and local figures for the percentage of women and children who received vitamin A and, in the case of women only, iron supplements. The distribution of vitamin A supplements to children is widespread, with figures similar to national rates. However, only a small percentage of pregnant women in the region received Vitamin A and iron following their delivery compared to national figures. The values for Humla are the lowest in the country overall.

Table 1 – Percentage of women and children who received vitamin A and iron supplements in Humla / Western mountains and Nepal.

Recipient	Vitamin A (%)		Iron (%)	
	Humla	Nepal	Humla	Nepal
Post partum mothers	5.7 [*]	29.4 ^{**}	9.5 [*]	23.2 ^{**}
Children 6-59 months	86.4 [*]	87.4 ^{***}	-	-

^{*} (Emeriau 2006), ^{**} (MOHP 2007), pg. 186, ^{***} (MOHP 2007), pg. 184.

An earlier anthropological survey of efficacy of supplementation and vaccination programs in Humla communities by Haddix-McKay et al. (2002), found that very few villagers were aware of the existence of national-level health initiatives such as the vitamin A program. Some could remember particular events, like a child receiving the distinctive red Vitamin A capsule but not a single parent could accurately and completely recall the vaccination or vitamin history of any child. A recent report by the Asian Development Bank (2009) was critical of the iron supplementation program, stating that the target group of pregnant and lactating women represented only 15% of anaemic women in Nepal. The regional figures stated previously show that even in the target group, distribution in remote areas is low. It was also mentioned that supplementation programs face many challenges such as cost, logistics and compliance.

Overall, all of these food aid programs provide temporary food relief rather than long-term improvements in food availability. The centralised nature of these

programs is not well suited to Nepal due to regional inaccessibility, which makes them cost ineffective and logistically difficult.

2.2.6 Nutritional status

Very little data exists on the nutritional status of local people in Humla, however that which does indicates prominent nutritional deficiencies. These include acute and chronic malnutrition caused by lack of bulk food and micronutrient deficiencies caused by lack of food diversity.

Acute and chronic malnutrition

Table 2 shows some results from a recent nutritional survey performed by ACF in Humla and Mugu (Emeriau 2006) showing the prevalence of global and severe acute malnutrition, and global and severe chronic malnutrition in children under the age of five.

Acute malnutrition is related to immediate food shortages (crop failures, droughts) and results in wasting, indicated by low weight-for-height ratios. Chronic malnutrition is an indication of long-term food shortages and results in stunting, indicated by low height-for-age ratios. Global terminology describes cases when either indicator (weight-for height or height-for-age) are less than 79% of the median of the reference population (less than two standard deviations), while severe describes cases where indicators are less than 70% of the median (less than three standard deviations) (deOnis & Blossner 1997).

Table 2 – Prevalence of global and severe and acute and chronic malnutrition in Humla, Western Mountains and Nepal.

	Humla & Mugu (%)		Western Mountains (%)		Nepal (%)	
	Global	Severe	Global	Severe	Global	Severe
Acute	12.3*	3.3*	11.2**	4.7**	12.6**	2.6**
Chronic	63.9*	37.1*	66.8**	32.2**	49.3**	20.2**

* (Emeriau 2006), ** (MOHP 2007)

The prevalence of acute and chronic malnutrition was found to be similar or higher than the national rate respectively, and, in the case of severe chronic malnutrition, higher than in all western mountain regions of Nepal. A follow-up study a year later (Fournier 2007) showed reductions in global and severe acute malnutrition to 10.1% and 1.3% respectively, indicating that the short term food

situation had improved. However, global and severe chronic malnutrition prevalence were still 68.5% and 35.5%, showing little or no improvement and indicating that the long term food situation is still insecure. Figure 14 shows local children in Humla with loss of hair pigmentation, considered to be a sign of Kwashiorkor (Latham 1997), a particular type of Protein-Energy-Malnutrition.



Figure 14 – Local Humla children with loss of hair pigmentation (photos – S Candy).

Micronutrient deficiencies

Micronutrient deficiencies were indicated by occurrences of anaemia and night-blindness. Anaemia is related to a lack of iron and night-blindness is a sign of vitamin A deficiency. Table 3 and Table 4 show figures indicating the prevalence of both of these among children under the age of five and post-partum women respectively, from the same ACF study mentioned previously. Although the values for anaemia are lower than the national rate, anaemia prevalence over 20% is considered a public health problem. Night-blindness prevalence was found to be higher than the national rate for both women and children. As a comparison, in developed countries, vitamin A deficiency is rarely found and anaemia prevalence in young children and post partum women is between 0 – 19% (Smith & Steinemann 2000; WHO 2008).

Table 3 – Anaemia and night-blindness prevalence in children under five.

	Humla & Mugu (%)	Western Mountains (%)	Nepal (%)
Anaemia	38.1 [*]	53.9 ^{**}	48.4 ^{**}
Severe anaemia	2.2 [*]	1.2 ^{**}	0.6 ^{**}
Night-blindness	1.5 [*]	-	0.27 [*]

^{*} (Emeriau 2006), ^{**} (MOHP 2007)

Table 4 – Anaemia and night-blindness prevalence in post-partum women.

	Humla & Mugu (%)	Western Mountains (%)	Nepal (%)
Anaemia	24.7 [*]	28.1 ^{**}	36.2 ^{**}
Severe anaemia	0.0 [*]	0.6 ^{**}	0.4 ^{**}
Night-blindness	20.8 [*]	29.4 ^{**}	12.9 ^{**}

^{*} (Emeriau 2006), ^{**} (MOHP 2007)

It is important to note that malnutrition, or under-nutrition in particular in this case, can be caused not only by inadequate nutrients in a person's diet but also by an inability to absorb nutrients due to illness. In Humla, the causes of under-nutrition have not been definitively determined. Poor sanitation conditions exist, which do cause illnesses such as diarrhoea, which affect nutrient absorption.

Results from the National Demographic and Health Survey in 2006 (MOHP 2007), however, show that intakes of vitamin A and iron rich foods, such as green leafy vegetables and red meat, are particularly low for women and children in the western mountains. In a survey of last-born children, only 8.7% had consumed iron rich foods in the 24 hours prior to the survey and only 51% had consumed vitamin A rich foods in the previous 24-hour period. The survey of post-partum mothers showed that only 10.9% had consumed iron rich foods and only 58.9% had consumed vitamin A rich foods in the past 24 hours. The figures for vitamin A food consumption for both women and children were the lowest in the country and the figures for iron consumption for women and children were the second lowest. These figures, combined with the prevalence of night-blindness and anaemia, and the sparse distribution of supplements, suggest that low intake is a significant contributing factor to the current nutritional deficiencies in Humla. The causes of these low intakes could potentially be attributed to smaller herds being kept due to the demise of the salt-trade and pasture availability, combined with the impossibility of growing vegetables over the long winter.

2.3 Problem definition and requirements for solutions

The previous sections presented an overview of agricultural conditions, accessibility issues, extreme weather and socio-economic status in the Humla region. This section discusses food security, or lack of it, as it applies to Humla, bringing together information presented earlier in this chapter and defining the overall problem. Following this, recommendations from previous research in Humla are presented to establish some general requirements for solving the defined problem.

In the case of Humla, both production and importation of food is inadequate, limiting food availability. There is little or no cash economy; therefore food that is for sale at markets is not necessarily accessible. Likewise, considering that food availability is a problem for most households in Humla, there is little scope to access food from social networks in times of shortage because it is likely that relations and neighbours will be experiencing similar shortages. Extreme weather in the region reduces agricultural production and restricts importation causing significant fluctuations in food availability and instability in the food system. Poor sanitation conditions and lack of development in Humla (i.e. health facilities) contribute to illness, reducing the ability of local people to utilize the nutrients in the food that is available. Therefore, according to the FAO definition, Humla can be considered to be food insecure, due to fact that sufficient food is unavailable and inaccessible, available food is under utilised and the food system is unstable. At these levels of food insecurity, households consume a poor and inadequate diet and undertake severe and often irreversible coping strategies such as reducing the size of meals, relying on wild crops that are time consuming to obtain, borrowing heavily from neighbours in the form of grain or money and selling assets (Khatrri-Chettri & Maharjan 2006; WFP 2010). All of these have long-term ramifications for health, education and availability of resources, which contribute to capability deprivation and entrenched poverty in an already poor and disadvantaged area.

Recent studies concerning the food and nutritional situation in Humla and the Karnali region make similar recommendations about how to address the problem. In the previously mentioned ACF nutritional survey in Humla, Emeriau (2006) stated that micronutrient deficiencies, especially anaemia, are still a nutrition concern despite national policy efforts. It is suggested that nation-wide nutrition

strategies are not adapted for conflict affected and remote area as most governmental structures cannot function properly in these specific zones. It was recommended to increase the quantity of foods available for people and to contribute in their diversification. A particular mention was made about conserving local fruit (as part of a nutrition program) so that it would be available all year.

In his extensive study of the food crisis in the Karnali region, Adhikari (2008) states that improving the production of locally suitable crops is necessary in the long term to increase food production and improve nutrition. He also states that to achieve this, there is a need for technological innovations that are suitable for the local agro-ecological conditions. He also recommends that an early warning or forecasting system be implemented to reduce the risk of extreme weather damaging crops. This indicates that protecting crops is necessary to improve food availability.

To increase local purchasing power and increase accessibility to food, Adhikari also recommends that programs to increase food production should go hand in hand with other income generating activities. A common method to achieve this is by producing high value cash crops such as vegetables, fruit and medicinal plants. Green leafy vegetables in particular would address two major nutrient deficiencies due to their high levels of vitamin A and iron.

The recommendations from both Emeriau and Adhikari are in line with those from a recent development report published by the FAO (Fang et al. 2007) which states that local food production is a key factor in achieving food security in remote areas. This report goes further to say that production per hectare of cultivated land needs to be increased rather than bringing more land under cultivation, which supports Adhikari's recommendation for technological innovation. In terms of development in general, a decentralised approach is recommended for remote mountain areas. For energy infrastructure for example, distributed energy generation systems are considered to be more viable than a central grid system (Karki & Shrestha 2002; Rijal 1998).

All of these recommendations suggest that an in-situ, decentralised approach is required to improve the food and nutrition situation in Humla. This includes technological innovation that will:

- increase local production on existing cultivated land.
- allow production of foods high in iron and vitamin A year round (such as leafy green vegetables).
- produce high-value cash crops such as vegetables.
- conserve summer crops such as fruit.
- reduce the risk of damage to crops from extreme weather.

In a remote, impoverished area such as Humla, with accessibility issues that not only apply to food but also to material goods, it is also important that any innovations:

- can be constructed and maintained with local materials and expertise
- can be managed within local cultural structures.
- are affordable for the local people.

Any food production solutions should also compliment existing water and sanitation and health programs in the district, contributing to addressing the overall food security problem.

2.4 Summary and Conclusion

In this chapter, background information on the Humla district was presented, with particular focus on aspects relating to agriculture, food and nutrition. These were discussed with respect to the concepts of food security, nutrition and poverty to define the problem and provide justification for research. Major aspects of the definition of food security and recommendations from past research were used to formulate a set of requirements for potential solutions.

From the information presented in this chapter, it can be concluded that Humla is an isolated, high altitude region with climate that is not well suited to agriculture due to extreme weather and topography. It has a significant population of over 40,000 inhabitants, which, in the past, it was possible to provide food for with

supplies brought to the region via ancient trade routes. The demise of these trade routes due to outside pressures, combined with difficult agricultural conditions, geographical and political isolation, political conflict and lack of infrastructure, mean that local food availability is currently a significant problem. Per capita cereal production is only 87 kg and there is an imbalance in food availability between seasons with cold conditions preventing most crops from being grown in winter, particularly fresh vegetables.

Food and nutrition aid is being delivered but again, geographical isolation, lack of infrastructure and outside influences, such as funding, mean that this is not an appropriate solution in the long term. Low GDP per capita of 186 USD further decreases accessibility to food imports. According to the FAO definition of food security, Humla can be considered to be food insecure, with poor nutrition contributing to entrenched poverty. The main nutrient deficiencies include vitamin A, iron and protein, apparent in the high rates of night-blindness, anaemia and stunting in the local population.

This indicates that availability and accessibility of food, and stability of the food system needs to be increased with a focus on improving nutrition and addressing the imbalance of food availability between seasons, particularly the most significant hunger period from January to March. The factors relating to the geographical and political isolation and socio-economic status of the area suggest that low cost, in-situ, de-centralised methods utilising local resources are required to improve agricultural production throughout the year and preserve any surplus in the good season. Recommendations from past research suggest that technological innovation is required to increase production from existing land. Prior crop losses due to extreme weather in the region, such as frost and snow, indicate that protected cropping methods could potentially ensure steady production. Cultivation of high value crops such as green leafy vegetables could increase income generation and address nutritional deficiencies. Since solar energy is abundant during the most severe hunger period, solutions incorporating passive solar design would potentially make the best use of available local resources. Possible solutions that incorporate these requirements will be discussed in Chapter 3.

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Chapter 3

*Appropriate technology and food
production in mountain areas*

3 Appropriate Technology and Food Production in Mountain Areas

Mountain regions in the developing world often have more in common with each other than with lowland people in their own countries. The most obvious commonalities are socio-economic systems based around subsistence and self-sufficiency, difficult agricultural conditions and availability of solar energy (Rijal 1998; Rozis & Guinebault 1996). In addition to this though, all have minority status within the state as a whole, whatever the country concerned, and are generally on the (natural) borders of countries. They are far removed from economic and political influence and almost always removed from cultural centres. Similar problems exist in terms of food security, nutrition and agricultural productivity (Akramov, Yu & Fan 2010; Jenny & Egal 2002; Rozis & Guinebault 1996).

Appropriate technology is a term that has a number of definitions in literature (Betz, McGowan & Wigand 1984, p. 3; Bourrieres 1979, pp. 1-7; Harrison 1980, p. 140; Jequier & Blanc 1983, p. 10). The common themes that emerge from them are that appropriate technology (AT) is now recognized as the generic term for a wide range of technologies that are suitable to the social, environmental and economic aspects of the location where they are used, by taking advantage of locally available resources, such as materials, labour and expertise.

In Chapter 2 food availability and nutritional problems in Humla were presented along with a discussion about the causes and effects of these problems. Following this, requirements for possible solutions were outlined based on recommendations from past research. These specified that in-situ, technological innovation is necessary to improve food production. A discussion of the local climate and food availability showed that solar energy is a significant resource during the most severe hunger period. The aim of this chapter is to present examples where solar technologies have been used to improve food availability in similar mountain areas, discuss their applicability in Humla and outline the limitations of current research and practice to predict the required nutritional outcomes.

Section 3.1 begins with a brief explanation about how these technologies work. Section 3.2 outlines current programs related to health and nutrition, and existing technologies that are being tested in Humla and reactions to and acceptance of these technologies. In Section 3.3, case studies are presented of established programs in other mountain areas with similar challenges where appropriate solar technologies, such as greenhouses and solar dryers, have been used to improve food availability. These include discussion of the designs and implementation methods. Following this, the applicability of these technologies and programs for Humla are discussed in Section 3.4 according to the requirements stated in Section 2.3. The limitations of current research and practice to predict nutritional outcomes are then explored as a prelude to further discussion in Chapter 4 (Research Design) about the formulation of the research methodology and methods.

3.1 Explanation of technologies

A basic greenhouse structure is essentially a “heat trap” (Garzoli 1988) that provides a suitably warm environment for growing crops when ambient conditions would not support growth. Solar radiation passes through the transparent covering, heating surfaces inside which then heat the indoor air via convection when it passes over them. The warm air is then not able to move away because it is trapped in the enclosed space. If the amount of solar heat gain exceeds losses due to conduction or air leakage, the air temperature in the greenhouse will become warmer than the surrounding air. In traditional greenhouses commonly used in developed countries, auxiliary heating is employed to maintain adequate growing temperatures. In areas where this is not possible, thermal mass, in the form of masonry walls or water tanks, is used to passively regulate temperatures. Excessive heat during the day is absorbed, stored and then released at night when air temperatures drop.

A solar dryer is a device for increasing the rate of drying of food, which allows excess produce to be safely stored for later consumption or transport to remote markets. It works in a similar way to a greenhouse, but also incorporates convection to create airflow and accelerate the drying process. Solar radiation passes through a transparent covering, heating surfaces inside which then heat the air. Vents at the top and bottom allow air to flow through, either via natural ventilation using the buoyancy of the warm air (passive system) or with some

form of forced convection or fan (active system). A direct solar dryer looks somewhat like a small greenhouse, with the glazed surface forming part of the drying cabinet and sun shining directly on the drying crop. An in-direct solar dryer has a separate solar collector where the air is heated, which then flows through an opaque drying cabinet. Solar dryers also sometimes have chimneys that further heat the exiting air to increase the effects of natural ventilation and the subsequent airflow.

While both greenhouses and solar dryers are deceptively simple, their success is based on a complex set of interactions between ambient conditions, crop physiology, economic and social factors.

3.2 Current programs and technology in Humla

As was discussed in Chapter 2, overall development in Humla is limited with little or no modern technologies and primitive agricultural practices. There are, however, some instances where technologies have been introduced.

The aim of this section is to present examples of existing agricultural technologies, greenhouses and solar dryers that are currently in operation in Humla.

3.2.1 Greenhouses

In Simikot, and some nearby villages, there are examples of small polyethylene structures and tunnel greenhouses used for growing vegetables (Figure 15).

Those in Simikot were introduced in 2004 by a Nepali NGO (Appropriate Technology Asia), while the tunnel greenhouses are believed to have been implemented by some local villagers, generally hotel owners. These structures are used only for frost protection and propagation and do not prolong the growing season significantly. According to Joshi and Gewali (Joshi & Gewali 2002), four box type dryers also exist in Humla and are used to dry apples, however none were sighted during fieldwork visits.



Figure 15 – Polyethylene structures in and around Simikot (photo - S Candy).

Two slightly more sophisticated greenhouse structures exist, one an hour walk east of Simikot and one near the village of Darapori, five hours walk northwest from Simikot. Both were constructed from corrugated fibreglass sheets with wooden support structure and had some additional thermal mass (apart from the soil) in the form of masonry walls. From discussion with local people it was determined that these greenhouses were implemented by outside NGOs as community projects, but it was not possible to determine the name of the organizations involved.

The greenhouse outside Darapori is believed to be used for seedling cultivation to extend the existing growing season and is still in use sporadically (Figure 16 – left). According to other villagers, the villager on whose land the greenhouse was built resented sharing his land with neighbours and began hoarding or misusing materials required for greenhouse maintenance, such as plastic and PVC pipe. The committee of villagers organized to regulate use of the greenhouse suffered from lack of investment in the project and passivity to the landlord's resentment. Their lack of use of the greenhouse also suggests that they were not sufficiently educated about the benefits and proper uses of the greenhouse, but the NGO is no longer active in the area, so its methods of implementation are yet unknown (Sanders 2010).

The greenhouse east of Simikot (Figure 16 – right) was used for vegetable cultivation, however the community based management of the project failed because only some participants were maintaining the greenhouse, while all

participants were benefiting from the additional produce. Eventually, those who were maintaining the greenhouse ceased to do so.



Figure 16 – Fibreglass greenhouses a) near Darapori (photo - S Candy) b) east of Simikot (photo courtesy of J Winger).

A more extensive implementation of appropriate technology has been undertaken by a local NGO, Rural Integrated Developments Services Nepal (RIDS Nepal). This organization runs a holistic community development program in the area focusing on providing basic amenities, such as water and sanitation facilities, solar electricity and improved cooking stoves, and running non-formal education and nutrition programs. As part of an aim to improve general food security, RIDS Nepal has installed a small number of simple greenhouses (Figure 17 – left and middle) and solar dryers (Figure 17 - right) in some villages. The greenhouses will be discussed here and the solar dryers in the following section.



Figure 17 – Greenhouses and solar dryers implemented by RIDS Nepal in Humla (photos – S Candy).

The greenhouses consist of three stone walls on the north, west and east sides and a south facing, angled, glazed polyethylene cover supported by timber

beams. In some cases, the back (north) wall had been built into the back of a terraced field for extra insulation from the surrounding soil. They are largely constructed from local materials, except for the polyethylene sheets. Of all the greenhouses, only one, constructed in 2004 at the High Altitude Research Station (HARS), from where RIDS Nepal conducts its development program, is suitable for year round cultivation (Figure 18).



Figure 18 – HARS greenhouse in April 2008, in front of RIDS Simikot office (photo – S Candy).

The HARS greenhouse is used by the RIDS Nepal staff to grow their out-of-season vegetables, which are mainly green leafy crops such as spinach. The design is simple with overall outside dimensions of 10 m by 5 m. The south-facing roof is inclined at 15 degrees. This slope was dictated by the height of the terrace at the back of the greenhouse and is far from ideal in terms of snow shedding or maximising penetration of winter solar radiation. There was also some shading at times of the year due to an adjacent building. The low profile of the building was also not ideal ergonomically, but the impact is minimized by short working periods. The walls are made of stone and mud, and the roofing frame is constructed from 75 mm by 50 mm timber. These are supported internally by vertical posts located in the ground. The glazing material is UV-

stabilised polyethylene imported from India. Until late December 2006, a single glazing layer was used. Subsequently, a second layer of polyethylene was installed. The greenhouse is irrigated using water channelled from the village spring via polyethylene piping.

Fuller et al. (2009) investigated the thermal performance of the greenhouse using data measured over the winter season. The conditions were found to be suitable, but not ideal, for growing certain vegetables. Based on simulation results, performance improvements such as plastic tubes filled with water for additional thermal mass (water heat stores), thermal screens and ventilation were implemented (Figure 19). Although conditions in the greenhouse are now better regulated, sub-zero overnight and excessive daytime temperatures still occur.



Figure 19 – Performance improvements for the HARS greenhouse (ventilation and water heat stores) (photos courtesy of R Fuller).

3.2.2 Solar dryers

The solar dryers introduced in Simikot and in some villages by RIDS Nepal are an indirect cabinet type made from galvanized iron sheets and Perspex glazing (Figure 17 – right). They consist of two separate parts: a glazed solar collector and an opaque drying chamber. Air is heated in the collector and then flows through the drying chamber where the product to be dried is spread on six trays stacked vertically above each other. Air exits the dryer through the chimney above the drying chamber. The dryers are manufactured in Kathmandu, flown to Simikot in pieces by aeroplane, transported to villages by animal and then assembled. This process is both costly and difficult, and at times dryer parts get damaged in transit.

Fuller et al. (2007) evaluated the technical aspects of the solar dryer and found it to be no more efficient than sun-drying and recommended an alternative design that could be constructed from more locally available materials at lower cost. The results of the investigations into both the solar dryer and the greenhouse indicate that further work is required to improve the performance of the two technologies.

3.2.3 Acceptance of technologies

For a technology to be appropriate, the acceptance and response by local people is particularly important. In an anthropological study, Sanders (2010) investigated the response to the introduction of greenhouse technologies in Humla. It was acknowledged that greenhouse projects are important for Humla but that the adoption of new technologies is extremely stressful for the subsistence population who are short on time, food and money for investment. Sanders found that villagers are receptive to new technologies but averse to risk. Lack of time and land prohibit the implementation of new technologies. Land is normally planted with crops with known yields, rather than risk with unknown crops and practices. For this reason, small scale greenhouse tunnel designs, that extend the growing season a small amount, were recommended for implementation in Humla because they require less time, space and labour and would be more acceptable to local farmers.

Sanders also found that community greenhouses with shared management were not suitable in Humla, since labour and resources often distributed unevenly in group settings. Technologies are generally managed within families and traditional divisions in a village and the organisation of group labour only creates an additional barrier to the proper use of technologies. Smaller scale designs were recommended to suit these traditional divisions and to reduce the risk involved in investing in new technologies.

Although these findings focus on greenhouse technologies, they have implications for the implementation and management of solar dryers also. It is clear that low cost and low maintenance designs that can be managed at a household level would be most appropriate for use in Humla. The recommended small tunnel greenhouse designs, however, do not allow year round cultivation. It was established in Chapter 2 that year round food availability is required to reduce imbalance between winter and summer and address nutritional deficiencies. This suggests that methods need to be developed to reduce the risk in introducing

larger technologies that will allow this, related to land use and crop yield and capital investment. Lessons learned from established greenhouse and solar dryer programs in other areas could potentially be implemented in Humla. These programs and their associated designs will be discussed in Section 3.3.

3.3 Established programs in other mountain areas

In mountain areas of China and India, solar greenhouses have been used to increase and diversify agricultural production (Dutta 1998; Pun et al. 2006; Rozis & Guinebault 1996; Zhang 1998). In the northern mountains of Pakistan and the Mustang region of Nepal, solar dryers are used to conserve surplus fruit from the annual harvest to be consumed during the winter or transported to markets for sale (Hussain 1998; Mirza, Maroto-Valer & Ahmad 2003). This section outlines the programs in these areas.

3.3.1 Ladakh, India

Ladakh is a high valley at over 3000m altitude in the Jammu & Kashmir province of India. It is surrounded by passes of up to 5000m, which are the only access for road transport. During the winter (November-May) these roads are blocked by snowfalls and the only means of travel or communication is by air (Singh 2000). The cost of fresh food brought in by plane is prohibitively expensive for local farmers, and, until recently, limited food stocks accumulated during summer were all that were available to eat over winter (Rozis & Guinebault 1996).

Over the last ten years, Groupe Energies Renouvelables, Environnement et Solidarités (GERES) has been installing and developing solar greenhouses in Ladakh (Figure 20). Initially the main aims were to limit food shortages during the winter season by encouraging the growing of leaf vegetables such as spinach, and to allow an increase in production to two harvests per year, through planting out under glass as soon as the soil was frost free. But it was also found that greenhouse produce could be sold locally, and therefore become a significant source of revenue for the population (Rozis & Guinebault 1996).



Figure 20 – Solar greenhouses in Ladakh (photos – S Candy).

The design itself resembles more a structure with large windows, than a conventional greenhouse. Thermal mass is incorporated into the greenhouse design to regulate temperatures day and night. The east, west and north walls, and narrow north section of the roof, are constructed from a double layer of locally made adobe blocks (mud brick) with straw insulation in between. These both store heat and insulate the greenhouse. The south face is glazed with polyethylene sheeting. According to Stauffer et al. (2004), green leafy vegetable production can be more than 50 kg per month for a 50 m² greenhouse, which is considered sufficient to feed a family and also to generate additional income.

The dissemination methodology used for the Ladakh greenhouse program has been documented by Rozis and Guinebault (1996). It has three stages: data analysis and program design; implementation of the program; and evaluation. The first stage involves gathering information on the specific area for the program, such as demographics, culture, climate, existing technologies, and local skills, and then designing an appropriate program for the specific context. The implementation stage involves first a year-long pilot program of the technology being implemented. This is to field test technology and determine if it is suitable for the capacity of local operators before large-scale dissemination begins. The final evaluation stage looks at the strong and weak points of the project according to evaluation criteria defined at the beginning of the project. This evaluation is undertaken so the research project can be repeated in the future. In the case of the Ladakh greenhouse program, the lessons learned related to site selection (proximity to water, slope, orientation, solar access) and design aspects (double walls / glazing in colder areas, higher roof slope in areas with snow, location of door on opposite side to prevailing wind, use of local masonry materials) were used to implement similar programs in other mountain areas.

This led to the development of a generic design with recommended adaptations for certain climates or sites, and the publication of a manual for the construction of high altitude greenhouses (see Stauffer et al. 2004).

3.3.2 Liang Shan, Sichuan Province, China

The Sichuan province is situated in southwest China. In general harsh climatic conditions prevail, with the mean temperature varying between -20°C and 16°C, with a nominal amount of rainfall and reasonable sunshine. The high heating demand is met mainly by burning fuelwood, which has resulted in deforestation, soil erosion, flooding and landslides. The diversion of animal dung from farm to hearth has also affected the quality of the soil and reduced agricultural production (Zhang 1998). Unlike most other parts of China, this area is considered a developing region according to the poverty threshold criteria (Rozis & Guinebault 1996).

In Liang Shan in the Sichuan province, it is estimated that around 3900 square metres of solar greenhouses have been installed, however it is not clear what percentage of these are functional (Zhang 1998). Overall most are of the “lean-to” design, which are attached to the side of houses and provide additional space heating as well as suitable conditions for agricultural production (Chen & Liu 2006).

Similar to the Ladakh design, these greenhouses incorporate thermal mass for heat storage in the form of solid rammed earth walls on the east west and north sides (which can be the wall of the dwelling also). Again, the glazed area is made from PE or poly-vinyl chloride (PVC) film to reduce capital costs. Thermal straw curtains are also incorporated to reduce heat loss at night or for shading during the day when solar radiation is very strong. According to Nan et al. (1994), in areas with a north latitude equal or less than 40 degrees, it is possible to produce foliage vegetables and some fruit vegetables such as cucumber and tomato in winter without supplementary heating. In areas with north latitude of 40-42 degrees, it is possible to produce foliage vegetables such as celery, Chinese chives and canola.

No details were found on the specific implementation methodology of the Liang Shan greenhouses, however, in general, appropriate technology programs in China are managed locally according to national guidelines (Zhang 1998).

3.3.3 Gilgit and Skardu, Pakistan

Gilgit and Skardu are located in the Northern Mountains of Pakistan. These regions are steeply mountainous with only a small amount of area suitable for cultivation. Most of the population are subsistence farmers who manage to meet only the bare minimum of food and fodder for their households (Hussain 1998). According to Hussain (1998) mountain areas in Pakistan are blessed with plenty of sunshine, with daily average solar radiation around four to six kWh/m².

Large amount of fruits, particularly apricots, are grown around Gilgit and Skardu. Due to the lack of logistics and basic infrastructure, much of the yearly crop would be wasted. Now, however, solar dryers are being used to preserve large quantities to transport and sell later in the urban market, resulting in a positive effect on the local economy (Mirza, Maroto-Valer & Ahmad 2003). According to the Pakistan Council for Renewable Energy Technologies (PCRET), in 2005 at least 150 solar dryers were in use, with 100 more proposed for the future (PCRET 2006). Local NGOs are also active in promoting solar dryers for drying fruit in mountain areas in order to develop this as a cottage industry (Hussain 1998). No data was found on the specific design of the solar dryers used in this area or the implementation methodology.

3.3.4 Lower Mustang, Nepal

The mountainous region of Lower Mustang is situated in the Upper Kali-Gandaki valley, north of the main Himalayan range, and where the climate is between that of Ladakh and Humla with average temperatures of 4.6 °C in winter and daily solar radiation of up to 27.4 MJ/m² (Blumenberg & Spinnler 2007). In the village of Marpha apple production has been promoted by the government since the 1960s to provide new sources of income (B R Sherchan 2008, pers. comm, 24 May). The inaccessibility of the area results in high transport costs if the apples are sold in nearby markets in Pokhara, making it impossible to compete with cheap imports from China and India.

Solar drying was introduced in the area not only to preserve excess produce but also to increase the value of the product. A combination of direct box type (Figure 21 - left) and indirect cabinet solar dryers (Figure 21 - middle) provided by the Nepalese Government through the Annapurna Conservation Area Project and a large scale solar tunnel installed by the Technical University of Munich (Figure 21 - right) are used to dry the annual over-production of ten tonnes of apples

(Whitfield 2000). The produce is then eaten out of season by local people or sold to tourists in dried form or reconstituted and used in restaurant meals.

Terminology related to types of solar dryers is often unclear, with some terms being used interchangeably for different designs. For clarity, the three different designs used in Mustang are described here. The box type dryer (Figure 21 - left) is the most simple dryer consisting of a rectangular box with a transparent glass or Perspex sheet and an insulated base. In Mustang the box is constructed from wood but can also be made from metal sheets. These dryers are naturally ventilated, with inlet holes drilled through the base and outlet vents in the upper parts of the side and rear panels. The combination of direct solar radiation and airflow dries the product. The design is based on that developed at the Brace Institute in Canada.



Figure 21 - Solar dryers in Lower Mustang: direct box type; indirect cabinet; large-scale tunnel dryer (photos – S Candy).

The indirect cabinet dryer (Figure 21 – middle) is similar to the design used in Humla (described in Section 3.1) except that it is fitted with a ventilation fan so it does not rely on natural ventilation alone. The large solar tunnel dryer (Figure 21 – right) is the only one of its type in Nepal and consists of a series of collectors and dryers arranged in a particular order. Air is heated in the collectors and flows over the products placed in thin layers. The solar collectors are tilted at 20° towards the south and have two layers of glazing made of UV resistant polyethylene sheets and blackened aluminium plates as absorbers. Air is pumped into the system using an electric blower or venturi unit attached to the exit of the dryer.

Both the indirect cabinet dryers and large-scale tunnel dryer were manufactured in Kathmandu, transported to Mustang by air and then assembled in the villages. Both designs require electricity to run ventilation fans, which is intermittently available in Lower Mustang. The box type dryers could be constructed in Mustang largely from local materials (i.e. wood) and were naturally ventilated so had no requirement for electricity.

Dissemination of solar drying systems was carried out by the Research Centre for Applied Science and Technology (RECAST) under the RETs in Asia program, financed by the Swedish International Development Agency (SIDA) and coordinated by the Asian Institute of Technology (AIT) in Thailand. The program was mainly aimed at promoting and creating awareness of solar drying technologies and the associated socio-economic benefits. This included the installation of several demonstration units and a series of training programs for manufacturers and operators (Joshi & Gewali 2002). Most of the dryers were purchased with the assistance of some form of subsidy, either from international donors or government institutions such as the Water and Energy Commission Secretariat (WECS) and the Alternative Energy Promotion Centre (AEP) (WEC 2000). All three designs were initially adapted from existing designs and then gradually improved through practice to make them technically viable and suitable for local conditions (Joshi & Gewali 2002).

A study carried out by the WECS (1999) found that more than 700 box type dryers have been installed in Mustang for drying apples. The box type is preferred because the initial costs are low and because they adequately serve the needs of households. Problems exist however with maintenance, such as warping of the wooden sides. Accordingly to 1999 data, only two indirect cabinet dryers were in operation and owned by wealthier local people such as hotel owners. However, at least four were observed during fieldwork visit in 2008 for this research project. Two tunnel type dryers exist, but only the one in Marpha is operational.

3.4 Applicability in Humla

In Chapter 2, it was established that Humla had significant food availability and nutritional problems. In Section 3.2 examples of existing solar technologies used to improve food availability in Humla were presented, but it was also established that implementation was sporadic, unorganised and that more work needed to be

done to improve the design, performance and operation of both the greenhouses and solar dryers. Anthropological research also indicated that any risk associated with the implementation of new technologies needed to be reduced for them to be acceptable to local farmers.

Section 3.3 showed that food availability had been improved in other mountain areas with similar climatic, socio-economic and accessibility conditions, using solar greenhouse and dryer technologies and a methodology that included location-specific design, an experimental based dissemination program and evaluation according to impact criteria related to increased food security and opportunities for additional income generation. This section discusses the applicability of the solar technologies in Humla, but also outlines how current research practice and methods are unable to predict the required nutritional outcomes.

As was presented in the case studies in Section 3.3, the solar greenhouses and dryers installed in Ladakh, Liang Shan, Gilgit, Skardu and Mustang are all examples of in-situ, technologically innovative solutions to increase food production and improve food security that utilise solar energy, an abundant local resource. The produce from the greenhouses helps to increase vegetable production, particularly in winter periods when local food is scarce, and the solar dryer helps to preserve excess produce from the warmer months to be consumed in the winter, both of which address the imbalance throughout the year. The production of higher value crops, such as vegetables, also provides an opportunity for income generation in the future. In the case of the greenhouses in Ladakh and Liang Shan and the box type solar dryer design in Mustang, they were constructed largely from local materials and with local expertise. These aspects satisfy the requirements defined in Section 2.4 for potential solutions, indicating that that they would be suitable to address the food problem in Humla, particularly since some examples of these technologies have already been introduced in the area. Implementation of the simple box type solar dryer design in Humla would also be in line with the recommendations of Fuller et al. (2007).

Due to the experimental nature of the implementation methodology used in the existing programs, however, it is not possible to determine definitively how these technologies would perform in the Humla context without instigating a time and

resource consuming pilot program. Even if tested over a whole year, the pilot design still may not encounter extreme conditions that occur on a less regular basis. The existing literature provides information about materials, construction and basic modifications for different climates, but not about how to estimate how much food could be produced and how this would improve nutrition, which was identified as a contributing factor to alleviating poverty in Section 3.1. Although numerous models exist to predict crop output for commercial greenhouses in developed countries (Cooper & Fuller 1983), these are not transferable to high altitude greenhouses due to the difference in design and construction. In addition to this, the complimentary nature of the two technologies to improve the stability of the food system and availability throughout the year has not yet been explored.

This suggests that a transferable method could be developed to predict crop output and nutritional outcomes related to the implementation of these appropriate technologies individually and together in different contexts. This would be an extension of the experimental implementation methodology developed in practice in Ladakh and the modelling of the thermal performance of the HARS Greenhouse by Fuller et al. (2009). It would combine these two methods and extend them to include both solar dryer and greenhouse produce, crop outputs and nutritional outcomes.

3.5 Summary and Conclusion

In this chapter, details about appropriate technologies used for food production in mountain areas were presented. This included greenhouses and solar dryers already in use or implemented in Humla, and the acceptance of these technologies, as well as successful designs used in other areas. Discussion of the implementation strategies for these technologies was also discussed where possible.

Experiences in other mountain areas show greenhouses and solar dryers were successful in improving food availability in remote mountain areas. Similarities between these regions and Humla suggest that greenhouses and solar dryers could be used to improve food availability and nutrition and contribute to improving food security. The greenhouse design used in Ladakh and the box type

solar dryer used in Mustang, in particular, satisfy the requirements stated in Section 2.4.

Current implementation methods are largely empirical, which provide good results but are time and resource consuming and not easily transferable. They also do not include capacity to estimate crop outputs and nutritional outcomes, or performance parameters to indicate how they may be improved. Existing models that do have this capacity are not suitable for the design appropriate to the mountain context. Therefore, to address the defined problem in Humla and to extend current knowledge, a predictive method is required to go beyond performance of the technologies to include crop production and nutritional contribution. The development of this method will be discussed further in Chapter 4 – Research Design.

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Chapter 4

Research Design

4 Research Design

Chapter 2 introduced Humla and the local and national issues relating to food availability and nutrition and discussed how poor nutrition is linked to poverty. Chapter 3 presented examples of how food availability issues had been addressed with appropriate technology, namely greenhouses and solar dryers, in similar mountain areas. The material presented provided a context for this research, defined the problem to be addressed, discussed possible solutions and outlined some general requirements for these solutions. It also showed how current research and practice falls short in its capacity to predict the required outcomes.

This chapter looks at the approach taken to investigate how appropriate technology, namely greenhouses and solar dryers, could address the nutritional outcomes in detail. It commences by setting out the research question, including a formal statement of the research hypothesis.

Having established the research question, the chapter goes on to consider the research methodology and scope of the research project. Following this, it outlines what methods might be used to capture the necessary data to answer the research question. This data includes quantifying current nutritional status and determining the potential nutritional contribution from greenhouse and solar dryer crops. This contribution will be determined by the crops selected and the amount of each that can be produced, which depend on the performance of the greenhouse and solar dryer.

4.1 Research Question

A review of the literature shows that nutritional problems in Humla are significant and caused by a lack of food and dietary diversity (as discussed in Chapter 2). Overall, agricultural production is insufficient to feed the growing population for the whole year. Although food production is generally adequate in the summer months, due to the availability of additional crops, significant shortages occur in the winter season. Most crops cannot be grown outside over the long winter and, due to lack of development, there is little or no infrastructure to store surplus produce from the warmer months. Access to imported food is also problematic due to the lack of roads, high transport costs and adverse weather. Poor nutrition

results in poor health, reduced ability to work, impaired mental development, and further entrenches the poverty cycle.

Current centralised food aid and supplementation programs have been shown to be largely ineffective in remote regions such as Humla, due to difficulties with transport and distribution. Recommendations from research in the area suggest that in-situ solutions need to be developed that focus on increasing the amount and diversity of local food available.

In other remote mountain areas with similar climate and accessibility problems as Humla, such as Ladakh in India and Mustang in Nepal, greenhouses and solar dryers have been used separately to successfully improve food availability. However, using the two technologies together in an integrated way to improve nutrition specifically has not yet been attempted. This led to the development of the research question:

How can greenhouses and solar dryers be best used in Humla to improve nutritional intakes of the local people?

Current research and practice falls short in its capacity to predict or estimate the potential for greenhouses and solar dryers to address food availability and nutritional needs in Humla and contribute to improving food security. Therefore the main aim of this research project is not just to investigate the potential for food production and preservation in greenhouses solar dryers, but also to develop a transferable method to do so. This will involve quantifying current nutritional status and determining the potential nutritional contribution from greenhouse and solar dryer crops through a combination of simulation and experimentation. This contribution will be determined by the crops selected and the amount of each that can be produced. Focus will be on the most severe hunger period from January to March, since this is the period when additional produce could significantly improve nutritional intakes. The solutions will also be required to operate within the constraints of palatability and according to the definition of appropriate technology given in Chapter 3.

4.2 Methodology

In this section the choice of methodology will be discussed. This is considered necessary in a multi-disciplinary project to justify the choice of methods and to provide a framework within which each of them will be applied. Following this, an outline of how the chosen methodology will be applied to this problem will be presented. The selection of each of the methods within this methodological framework will be discussed in Section 4.3.

Methodology, by definition, refers to a system of broad principles from which specific methods or procedures may be derived to interpret or solve different problems. It is the branch of knowledge that deals with method and its application in a particular field of study (Evans & Gruba 2002). Therefore, to choose an appropriate methodology, it is first necessary to define the nature of the problem to be solved. According to Jackson (2003), a system can be classified as ranging from simple to complex with relationships between participants defined as unitary, pluralist or coercive, where participants are defined as those with an interest in the problem (Figure 22). Both the complexity of the system and the relationship between the participants are important to understand when selecting appropriate methodology and methods.

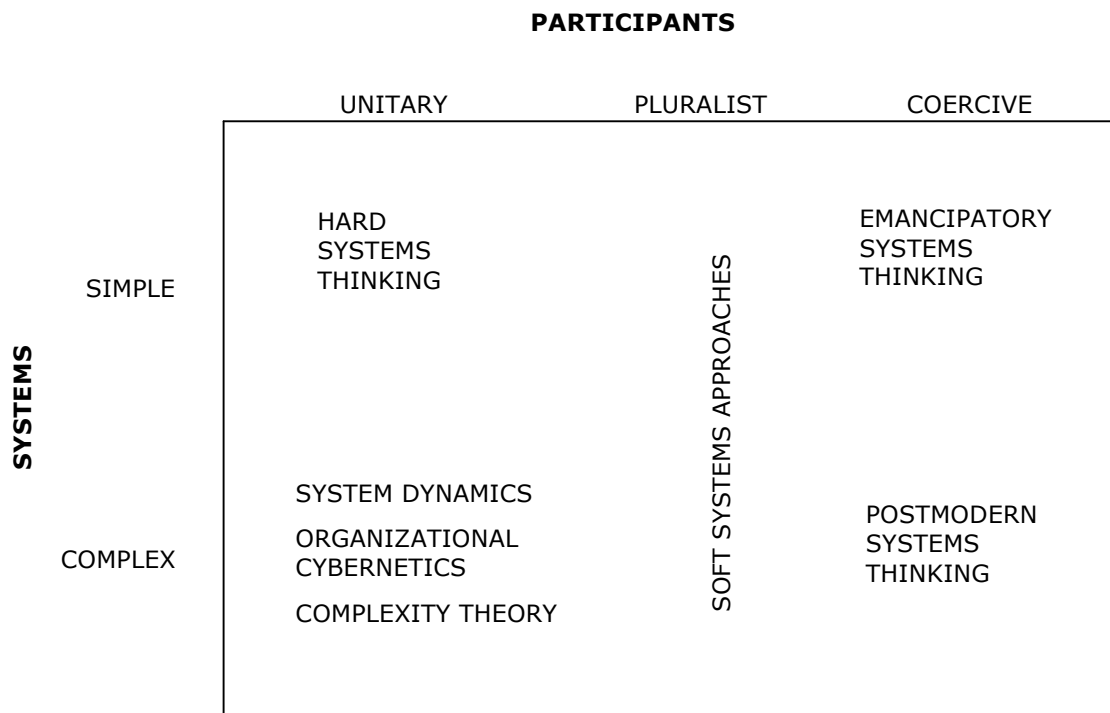


Figure 22 – Grid of problem contexts and associated systems approaches or methodologies (Jackson 2003).

A simple system can be characterized as having few subsystems that are involved in only a small number of highly structured interactions. At the other end of the scale, extremely complex systems can be characterized as having a large number of subsystems that are involved in many more loosely structured interactions, the outcome of which is not predetermined. A unitary relationship between participants indicates a common purpose, i.e. that they have similar values, beliefs and interests. A pluralist relationship between participants differs in that, although their basic interests are compatible, they do not share the same beliefs or values. A coercive relationship indicates few interests in common and would hold conflicting values and beliefs. Compromise is not possible, so no agreed objectives direct action.

The problem to be solved (as stated in the research question Section 4.1) is to improve nutrition in Humla using greenhouses and solar dryers. The main stakeholders or participants include the local community, local NGO, RIDS Nepal and engineering researchers. Although there is a common interest between participants which could allow a hard systems approach, appropriate technology problems in general are not purely technical and must incorporate “softer” cultural and social aspects of the context in which they operate. Since technical and social aspects can be contradictory, and more than one type of solution is possible, the participants can be considered to be pluralist since the best technical solution may not be acceptable or operable for local people. This is illustrated by the examples of the failed implementation of large, community managed greenhouses in Humla outlined in Chapter 3. Although a large shared greenhouse was better for thermal performance and was more cost effective, it required communal management which did not suit local cultural structures. According to van Gich (1979), a hard systems methodology or approach, is insufficient to solve a pluralist problem since it does not include methods to determine criteria, compare individual preferences and achieve consensus between participants and acceptance of the solution. Instead, a socio-technical methodology is required such as applied systems analysis and applied general systems theory.

According to Miser and Quade (1985) however, a scientific or hard systems approach can be applied to a socio-technical problem once the problem is

properly formulated and a clear goal defined. The social aspects then become requirements or constraints in a hard systems problem. In this case, the appropriateness of the technology has already been established through practice in other similar areas and criteria or requirements have been established by studying the resources available. By working closely with a local organization, common values have been established and consensus has been reached. The installation of some forms of the technologies in the area indicates acceptance. Therefore the problem can be considered to be unitary and a hard systems methodology is suitable.

The most common hard systems methodologies include the scientific, engineering or operations research (OR) and systems analysis or engineering. The description of the scientific and engineering or OR methodologies by van Gigch (1979) are represented in Figure 23.

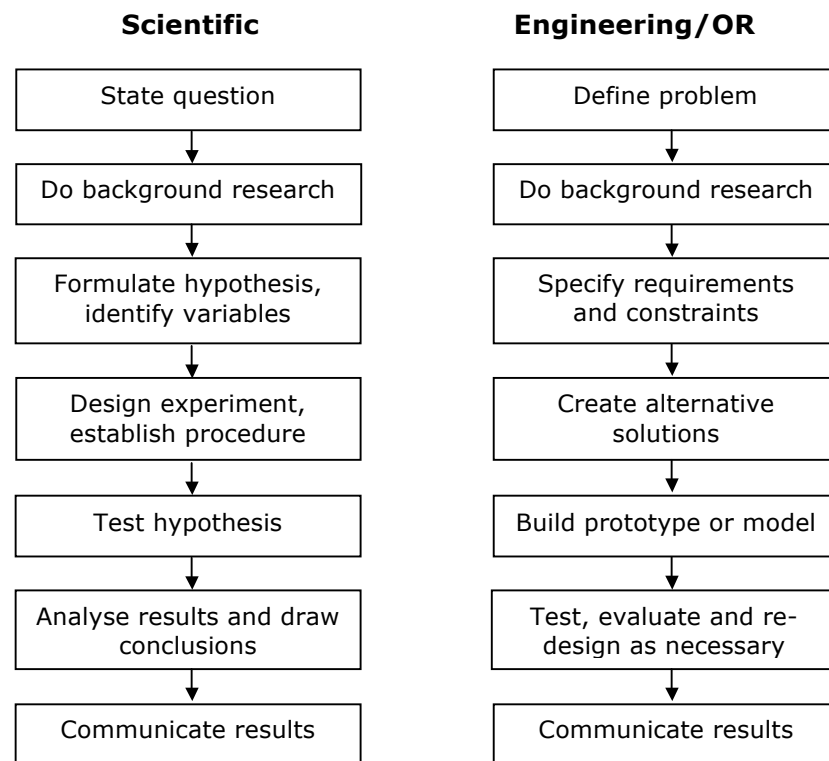


Figure 23 – Hard systems methodologies a) scientific b) engineering / OR.

Since this is an applied research problem, focused on specific outcomes and solutions rather than just furthering knowledge in a particular field, the traditional scientific methodology is not considered suitable since it does not include the

potential for review and re-design of alternative solutions. The engineering or OR methodologies are suitable for applied problems, but are mostly used for well-structured problems whose attributes are specific and well defined. They do not necessarily include the human aspects for a socio-technical problem.

The classic systems analysis and systems engineering (SE) methodologies were developed for real-world, applied, socio-technical problems (Jackson 2003), essentially an evolution of the engineering and OR methodologies. These look at the problem as a whole to meet the immediate need while still considering the influence of a range of environmental factors, and includes the consideration of some soft-system components. The SE methodology can be characterized as the application of the OR methodology at the level of the entire system and at that of each of the sub-systems. Since this project has sub-systems including construction of each technology, operation of each technology and crop selection, all of which interact to contribute to the overall outcomes of improving nutrition, SE is considered to be the most suitable methodology for this appropriate technology problem. Figure 24 shows the methodology for this project that incorporates aspects of the of the systems analysis methodology as defined by Jackson (2003, p. 53), and systems engineering approach as defined by van Gigch (1979).

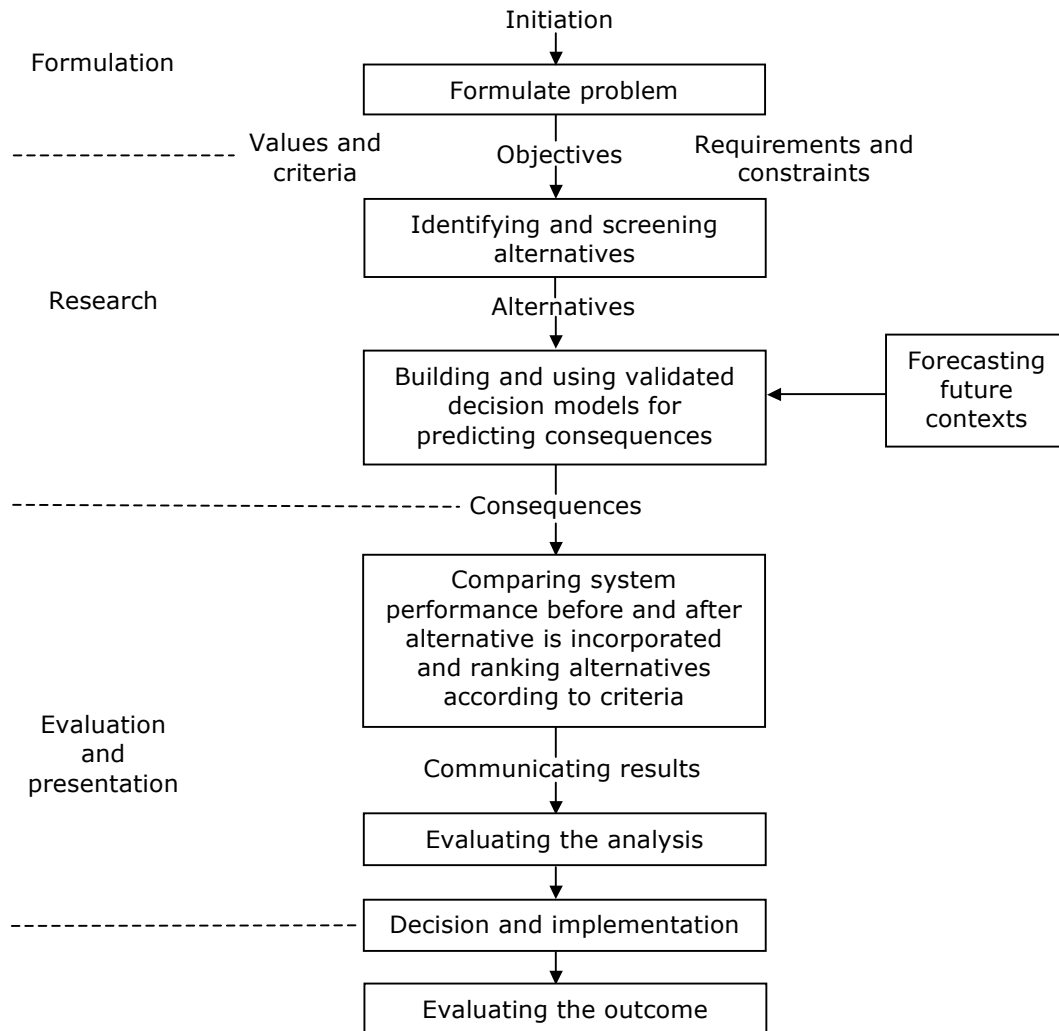


Figure 24 – Project methodology based on systems engineering and systems analysis methodologies.

This choice of methodology defines the scope and focus of this research project. Although this project incorporates a number of multi-disciplinary factors, relating to nutrition, plant physiology and food science, which will affect the outcomes, the main focus will be on technology required to achieve or contribute to these outcomes. Covering all these factors in experimental detail would be outside the scope of this research project, therefore considered assumptions will be required to quantify the criteria, requirements, constraints and models. Although some problem formulation is discussed, this project is mostly concerned with the research and evaluation and presentation sub-sections of the methodology.

The methods employed for each section of the methodology for each subsystem will be discussed in Section 4.3.

4.3 Methods

In this section, the specific methods employed to address each part of the methodology and each sub-system are discussed. The nature of the methods chosen is related to the complexity of the problem. In a very simple problem with few sub systems and well-understood interactions, a computer model would be considered sufficient to predict outcomes. In a very complex problem with a large number of sub-systems, uncertainties and loosely structured interactions, predictions are extremely difficult to make and largely experimental methods, at full-scale performed and in context, would be required to predict outcomes. This problem involves a number of different interactions, some of which are well understood and some of which are not. It also involves a number of uncertainties related to the remote location, construction methods and availability of resources. It can be considered to be moderately complex, therefore it is considered suitable to use simulation and modelling in conjunction with experimentation at full scale in the actual context to validate the model. It is believed that this will provide a good balance between achieving sufficient accuracy and reducing the amount of time required to be spent in remote areas.

Table 5 shows how the research methodology is applied to the whole system (overall) and to each subsystem (crop selection, design and construction, operation). As mentioned previously, it is assumed that the values are common between stakeholders/participants and therefore no methods are required to determine these. The three main sets of criteria against which results will be compared are nutritional, “appropriateness”, and performance criteria. Nutritional criteria refer to the nutritional deficiencies that are to be addressed and their quantitative value. Appropriate criteria are the local constraints within which the technologies must operate. Performance criteria are the conditions necessary for crop production and preservation.

The requirements, constraints and alternatives have been determined through a combination of fieldwork and a literature review. Fieldwork was necessary since information on these aspects is often not published. General requirements and constraints are outlined at the end of Chapter 2, while more specific aspects are

addressed in the chapters dedicated to each sub-system (Crop selection – Chapter 5, Design selection and construction – Chapter 6 and 7, Operation – Chapter 5 & 8). Further discussion about the selection of alternatives occurs in these chapters also.

The methods discussed in this section include those integral to building a quantifiable and transferable system. These include the method necessary to measure nutrition from food consumed to determine the initial nutritional gap and the potential contribution from produce from the solar technologies, to select appropriate crops and their distribution and to estimate the crop output from each technology. These all involve a combination of fieldwork, literature review, experimentation and simulation. An outline of these methods will be provided here, with further detail in the abovementioned chapters. Alternatives will be compared using a parametric study, where the performance of each subsystem will be compared before and after implementation of each alternative. These performance results will then be used to determine the overall best combination of alternatives to improve nutrition.

The subsystems will interact with each other in the following way:

- Initially, the Crop subsystem will be used to determine a short list of potential crops to be produced in the solar dryer and greenhouse and the best size for the greenhouse.
- Information from this process will be used in the Design Selection and Construction subsystem, along with other information, to decide what designs should be built.
- The actual crop yields will then be used as inputs into the Crop subsystem again, to determine the best distribution of crops.
- The experimental data gathered from the testing of the constructed design will then be used as a benchmark for the Operation subsystem to explore the effect of alternative operation methods and materials, via modelling, on the performance of the technologies with the aim to improve growing and drying conditions.

Table 5 – Application of methodology to overall system and sub-systems.

	Overall	Crop Selection	Design selection and construction	Operation
Objectives	To improve nutrition in Humla using greenhouses and solar dryers.	To choose best combination of greenhouse and solar dryer crops to improve nutrition	To choose an appropriate design to produce or preserve additional crops	To determine best operation procedure for chosen design to produce or preserve additional crops
Values and criteria	Having sufficient, palatable, self-produced food. Compare to importing food?	Are the chosen crops palatable and nutritious? Are they already grown locally? Current nutritional deficits	Is the cost worth the benefits? Can it be built locally? Are the benefits understood? Current yield data	Is the time cost worth the benefits? Are the benefits understood?
Requirements and constraints	In situ solution that is quantifiable, transferable and acceptable to local people.	Local crops already grown and eaten in Humla for which nutritional data is available. Palatable combination of food.	Selection from designs already used in mountain areas. Use of local materials and local expertise for construction. Low cost, appropriate design.	Operational with local expertise, within local time constraints and within village cultural structures.
Alternatives	Combinations of crops, technologies and operation	Choice of crops, growing area of each (in greenhouse),	Designs, construction materials, construction process, design attributes such as wall thickness and double-glazing (for greenhouse).	Ventilation, thermal screens (greenhouse), loading ratios, thickness of samples (solar dryer)
Models	Combination of models to estimate nutritional contribution based on crop selection, distribution, and environmental conditions.	Linear programming model using yield and nutritional data to estimate the combination of crops that will give the best overall nutritional improvement.	TRNSYS ¹ model, plant growth model and crop drying model to estimate which design features will give the best yield.	TRNSYS ¹ model, plant growth model and crop drying model to estimate which operational procedures will give the best yield.
Comparing and ranking alternatives	Overall parametric study	Comparison of nutritional outcomes based on crop output data from TRNSYS ¹ model and distribution of growing area.	Comparison of performance and estimated yields before and after implementation of each alternative.	Comparison of performance and estimated yields before and after implementation of each alternative.
Evaluating analysis	What combination of crops, technologies and operation gives the best overall nutritional outcome?	Which combination give the best overall nutritional outcome and the most palatable combination? (based on crop output of technologies)	What combination of choices gives the best crop output for the lowest cost? Best value?	What combination of choices gives the best crop output for the least time? Best value?

¹ TRNSYS model refers to a mathematical model of the thermal aspects of technologies used for simulation purposes.

4.3.1 Measuring nutrition

To determine extent to which nutrition is improved by the implementation of greenhouses and solar dryers, it is necessary to quantify the existing nutritional intakes and the nutritional contribution of additional food. The following section discusses potential methods that could be used to achieve this.

According to DeRose and Milman (1998), two methods exist to determine nutritional deficiencies and hunger. The first method focuses on whether people are getting enough to eat. It involves a comparison between the diet actually consumed and that required to sustain good health and normal activity, growth and development. This is measured either with a consumption or intake survey, which requires a family member to recall what food has already been eaten, or an expenditure or supply survey, which surveys how much is spent on food and the value of that food. The nutritional content of the food and the estimated quantities are then combined to determine the nutritional intake. Significant difficulties can be encountered, however, with practical implementation with respect to measuring or estimating the diet and defining the requirements against which it should be compared.

The second method focuses on the outcomes of malnutrition and has the advantage of identifying people whose intake is poor enough to have measurable consequences. It avoids the necessity of measuring either intake or need. A disadvantage is that it is not always clear that inadequate intake accounts for the outcome measured since some manifestations of hunger have other causes. In addition to this, simple malnutrition monitoring techniques rely on traditional anthropometric data (weights and charts) and may not be able to detect micronutrient deficiencies (George, Latham & Abel 1992).

For the purposes of this research, the first method was used taking data from production or consumption surveys, since it focuses more on amounts and nutrient composition of food, rather than its economic value. It was also chosen based on availability of data on food consumption in Humla, the national prevalence of micronutrient deficiencies in Nepal (MOHP 2007), and the fact that the contribution of additional food from the greenhouse or solar dryer can be easily incorporated. If data specific to Humla was not available, data from the neighbouring Mugu district was used, since it is geographically, culturally and

demographically similar to Humla. Further explanation of food availability and consumption data, assumptions relating to nutrient content and crop yields can be found in Chapter 5.

4.3.2 Crop selection and distribution

The method used for crop selection and distribution is outlined here. It includes the rationale behind crop selection and the method used to determine the best distribution of selected crops.

The alternatives for crops for the greenhouse and solar dryer will be chosen based on how well they meet the nutritional needs but only selected from those currently grown in the area. Even though other crops from other areas might better address the nutritional deficiencies, it is thought that the lack of local experience in growing these crops could affect potential yields. Local people may also be unwilling to change their food patterns and would therefore not accept foreign crops. In addition to this, introduction of foreign crops could adversely affect the local eco-system.

To explore which crops would be most suitable and estimate the quantities, and growing area required, a mathematical modeling technique, linear programming, will be used. A linear programming model involves maximizing or minimizing a particular objective (in the form of a linear function based on the problem parameters) that is subject to linear constraints. This is a method that has been widely used in agricultural and human nutrition applications, from farm planning to the design of palatable diets for populations (Dent, J, Harrison, S & Woodford, K 1986; Foytik 1981). In most cases the objective is to optimize for cost, to either increase profits for farms or to reduce costs of nutritious diets. It was used here to determine the combination of potential crops that will deliver the best overall nutritional improvement based on available resources. The supporting data has been gathered from a combination of a review of literature and fieldwork in mountain areas and the model will be constructed using MATLAB, an engineering simulation software program. A limitation of this method is that the objective function and constraints must be linear equations.

The main parameters in this problem are growing area, available labour and crop yield data per unit of growing area. Further detail on the linear programming model is presented in Chapter 5. The model will first be used to select a sample

of appropriate crops and their distribution, and determine the size of the greenhouse and dryer, based on nutrient and yield data obtained from a literature review and palatability criteria determined from fieldwork. Once a validated model to predict crop output has been constructed and tested with different alternatives, the estimated yield data will be updated in the linear programming model. The analysis will be re-run to determine the best overall improvement in nutrition.

4.3.3 Technology design selection and improvement

The selection and performance improvement process of the greenhouse and solar dryer designs is similar to that of the crop selection and distribution process.

Alternatives for designs were limited to those already in use in other mountain areas. Most established greenhouse designs in use in the developed world have high glazed to opaque surface ratio, little thermal mass (apart from the floor) and require auxiliary heating. High altitude greenhouses in Ladakh and China differ substantially from these designs in that only the roof and less than half of the walls are glazed and substantial amounts of thermal mass are incorporated into the side and back walls for passive temperature regulation. These structures resemble more a typical house with large windows than traditional greenhouses.

In addition to this, substantial experimental work has been done by Stauffer et al. (2004) to adapt the original Ladakh design for different mountain areas, leading to the development of different design attributes for various climates and suggestions for alternative materials. It was decided to follow the recommendations in their published manual for the initial design with some small changes according to availability of local materials and advice from local tradespeople.

Testing and improvement of the design will be done with a combination of experimentation and simulation. As discussed in Chapter 3, the adaptation of the greenhouse design in Ladakh was achieved largely through experimentation with review and refinement following small-scale dissemination. Although effective in each area, this method was not transferable to other areas and required large amounts of time spent in remote locations. In another example of technology design improvement, Hochman and Lowrey (1996) employed modelling and parametric studies alone to evaluate strategies for potentially enhancing thermal

performance of Chinese greenhouses in Shandong province. Although reasonable results were produced without fieldwork in remote locations, it was acknowledged that they are not entirely accurate. This is due to uncertainties related to actual building heat loss (particularly thermal conductance of walls that may vary in composition) differences in building usage and the fact that different simulation codes can exhibit wide discrepancies in analysing an identical simplified building model, while also exhibiting different sensitivity to parametric changes.

For both the greenhouse and solar dryer, selected prototypes will be constructed and tested in Humla, to determine that they satisfy the “appropriateness” criteria. The experimental data will then be used to validate simulation models, with which improvements to the design will be made. The aim of this process is to address both the performance criteria for each technology (if it has not already been met) and the overall nutritional criteria.

According to Fuller et al. (2009) numerous dynamic thermal models have been developed to investigate the thermal performance of greenhouses (Cooper & Fuller 1983). Most of these were practiced in industrialised countries and have been developed for the traditional greenhouse structures discussed previously. The proposed Humla greenhouse design will have more similarities to a traditional building rather than a greenhouse. Cropping levels will also be low compared to a modern greenhouse practice. For the above reasons, a more traditional building model will be used to investigate the greenhouse thermally rather than a specialist greenhouse model. The standard building sub-routine within TRNSYS (Type 56) has therefore been used. TRNSYS is a solar simulation program that is used extensively for simulating the performance of solar energy systems. It is a user-oriented program that permits the user to interlink component models normally associated with solar energy systems. The Type 56 component allows the user to define a building of any size or shape. User-supplied parameters define material properties and dimensions. Schedules can be used to determine inputs at specified time and a radiation processor component within TRNSYS uses horizontal radiation data to calculate hourly values of solar radiation on all of the building's surfaces.

TRNSYS will also be used to model the solar dryer. Currently no generic solar dryer component exists in TRNSYS, so a model will need to be developed. This

will not only allow design improvements to be simulated for this project but will also contribute new knowledge in this field of research.

In most cases, parameter values for each model will be determined based on those available in literature, with some others related to the operation of the technologies being determined during the experimentation process. As mentioned previously, the output from the models will be validated using experimental data from the prototypes constructed in Humla. Further detail on the design of the TRNSYS model can be found in Chapter 8.

4.4 Summary and Conclusion

In this chapter the research design has been outlined including a statement of the research question, choice of methodology and related methods that will be used to answer it. The socio-technical problem of improving nutrition in Humla with greenhouses and solar dryers will be addressed with a hard systems methodology similar to that of the common systems engineering process, with soft-systems aspects incorporated as constraints. This choice of methodology has implications for the scope of the project and for the choice of methods used to investigate the problem. As a result the methods used within this will be a combination of experimentation and simulation, focusing on the technological and quantitative aspects of the problem.

The design of the research instruments, namely the linear programming model and the TRNSYS building model will be outlined in Chapters 5 and 8 respectively.

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Chapter 5

Nutrition and Crop Analysis

5 Nutrition Intakes and Crop Analysis

In Chapter 2, the causes and effects of a lack of food in Humla were outlined and it was established that there was a distinct imbalance between the food available in the warm season and the cold season. In Chapter 3, potential appropriate technology solutions used in other areas to improve food availability were explored, with the conclusion that an in-situ solution involving solar greenhouses and dryers could best suit the requirements in Humla. In Chapter 4, the research methods and sub-systems that will be used to investigate this possibility were outlined.

The aim of this chapter is to outline the Crop Selection sub-system and present initial results. Firstly, a detailed quantitative estimate of current nutritional intakes for a typical family in the winter hunger period is presented, establishing nutritional “gap” criteria to inform decisions for crop selection and against which later results can be compared. Following this, crop alternatives are chosen based on local availability criteria. The nutritional impact of different combinations of crops is then explored to determine the combination, distribution and scale that would provide the best nutritional and appropriate outcome. This is done using a linear programming model based on crop yield data from existing projects, literature and harvest information gathered during fieldwork in the area and a multi-variate analysis. The focus of this analysis will be on the months of January, February and March, since this is when the most severe hunger period occurs. It is also centered on addressing nutrition and palatability requirements, and not including surplus for sale and income generation.

These initial results are intended as a starting point for further research, to determine which crops would be most suitable and estimate the quantities required prior to experimentation and determine which nutritional deficiencies can be realistically addressed. Due to the lack of food data and difficulty in determining nutrient content of food and nutrient uptake, it is not intended as a comprehensive nutritional survey. Once the analysis of the performance aspects of each technology has been completed, and yield data estimates specific to Humla have been established, the linear programming model will be used again to determine overall improvement in nutrition based on results from all sub-systems.

5.1 Current Food and Nutrition

In this section the current nutritional shortfalls for selected nutrients are estimated to establish nutritional criteria. This has been based on the concept of nutrient adequacy rather than nutritional status. Nutritional status is defined as the levels of nutrients in the body and the ability of those nutrients to maintain normal metabolic integrity (Bender 2005). It is determined by individual intake, requirements and utilization of nutrients (Jeejeebhoy, Detsky & Baker 1990) which are affected by food related and non-food related factors, such as processing and cooking and health and sanitation. Status with respect to individual vitamins and minerals is normally determined by laboratory tests, either measuring the blood and urine concentrations of the nutrients and their metabolites, or by testing for specific metabolic responses (Bender 2005). Nutrient adequacy refers to the achievement of recommended intakes of energy and other essential nutrients. Since this research is focused on food production rather than anthropometry, nutrition criteria based on nutrient adequacy was considered to be more suitable when assessing how agricultural technologies could contribute to improving nutrition in Humla.

Measurement tools used to assess nutrient adequacy are the Nutrient Adequacy Ratio (NAR) and the mean nutrient adequacy ratio (MAR). The NAR is defined as the ratio or percentage of intake of a particular nutrient to its recommended nutritional intake (RNI) and the MAR is the average of the NARs. This is computed by summing the NARs and dividing by the number of nutrients. Each NAR is usually truncated at 100 percent of the RDAs to avoid high consumption levels of some nutrients compensating for low levels of others in the resulting MAR. The concept was first developed by Madden and Yoder (1972) and has since then been used both in developed and developing countries (Guthrie & Scheer 1981; Hatloy, Torheim & Oshaug 1998; Krebs-Smith et al. 1987). For Humla, nutrient adequacy has been measured over the winter season from January to March, as this was considered to be the most severe hunger period. Although an additional hunger period occurs prior to the summer harvest, this is largely classified as such due to the availability of grain. Additional vegetable produce during this period is generally sufficient to provide adequate nutrition (see Chapter 2, Figure 13).

The basic Humla diet consists of a two meals per day, including a starchy staple food such as rice or flat bread (roti), thin lentil soup (daal) and a serve of cooked, spiced vegetables (thakuri), usually potatoes and green leafy vegetables. Occasionally, raw carrot, onions or cucumber are eaten with the meal. However, due to the agricultural, food storage and accessibility conditions, there are times when many of these meal components are not available. Meat is eaten rarely, mostly reserved for festivals and special occasions. Some variation occurs in diet between ethnic groups. In Buddhist villages the typical diet includes additional grain, beef and dairy products. Since the Buddhist population is a minority ethnic group comprising only 16% of the Humla population (Emeriau 2006), it is considered safe to assume that the majority of poor families in Humla eat mainly rice, roti, daal and thakuri.

Available nutrients from food were calculated on a household or per family basis as the household is the basic unit in which food is consumed in most settings and also best suits the traditional division of labour according to Sanders (2010) for management of technologies. Based on observations made during fieldwork, the statistics of Emeriau (2006) and field survey data from Adhikari (2008), it was assumed that an average poor family has six members; an adult male, an adult female, three children of varying ages (1-3, 4-6 and 7-9 years old) and a breast feeding baby less than six months old. Families with older children capable of working in the fields alongside their parents tended not to be as food insecure as those with young children only, so the typical poor family was considered to have only children under the age of ten.

Using the results of a food availability study conducted by RIDS-Nepal in March 2007 and additional research, it was possible to summarise the type and amount of food consumed daily by the family members over the evaluation period. The figures from the RIDS survey are shown below in Table 6. This food consumption data was obtained using the "intake" technique, which requires a family member (normally the mother) to recall what food has actually been eaten over a previous period. The quantities were estimated based on discussions with RIDS staff and observation in some households. The values for rice, roti and daal refer to quantities in cooked (not dried) form. The figures for rice were in dried form in the original survey but were multiplied by a conversion factor of 2.32 (Banjong, Viriyapanich & Chitchang 1995) to convert them to cooked form.

The lack of vegetables, meat and dairy products in the winter diet indicated by survey data was verified during fieldwork in March 2008. For vegetables this is based on the fact that conditions are too cold to grow them and because it is prohibitively expensive and often impossible to import them. For meat and dairy products, it was observed that very little of these foods are eaten on a regular basis. This is verified by national average figures relating to energy intakes which show that meat and milk products constitute only 1.4% and 3.4% respectively of the total dietary energy supply (FAO 1996c).

The figures for rice and roti appear to be particularly low compared to what was observed during fieldwork. A review of studies related to calorie intake versus income by Bouis and Haddad (1992), had an additional finding that there is a general tendency for lower estimates to be derived from the "intake" method of food surveying. Additional research was therefore done to verify these figures.

The amounts stated for rice consumption in the original RIDS survey were based on the fact that each family receives 5.5 kg of subsidized dry rice each month (66 kg per year) supplied by the NFC⁶. This does not take into account additional rice supplied by the World Food Program (WFP) to the poorest families of approximately 32 kg per beneficiary per year (Adhikari 2008, p. 182). Based on fieldwork observations and results from a field survey in neighbouring Mugu district and the Karnali region (Adhikari 2008, pp. 36, 202), it was assumed that little or no rice was produced locally for ecological reasons. In total, the rice available for a family of six is assumed to be 258 kg per year or 717 grams per day.

According to FAO estimates (Fang et al. 2007), the per capita cereal production in Humla is 87 kg per year, which equates to 522 kg per household per year or 1430 grams per household per day. These estimates are obtained by first calculating the amounts of specific foods available for human consumption within the region and then subtracting losses due to processing, transport and the amounts used for purposes other than human consumption (animal feed, seeds, etc). Figures obtained from a field survey by Adhikari (2008, p. 220) for the

⁶ According to Adhikari (2008, p. 181), based on figures from the NFC Sales Department, the NFC supplies 17.75 kg of rice per capita per year (106.5 kg per family). But according to Seddon and Adhikari (2003), up to 60% of the supplied rice is used to feed government employees rather than local people, which accounts for the lower figure stated in the RIDS survey data.

Karnali region, show that a poor family has 367 kg of cereals available for consumption per household per year, or 1005 grams per household per day. This lower figure was considered to be more realistic for a poor family in Humla and supports the assumption that a family such as this would receive WFP donated rice.

Based on the previous assumption that little or no rice is produced locally, the cereals included in the FAO estimate are assumed to be comprised of a combination of local grains. These include wheat, maize, uwa, common millet, kaguno and chino (both of which are forms of millet). It is assumed that all the grain available for consumption is used to make roti only and that the grain available makes the equivalent weight of roti.

These values for rice and grain production found in literature are higher than those stated in the RIDS nutrition survey and are considered to be more realistic because they take into account additional sources of food and also because the RIDS data was collected using the intake method which tends to produce lower estimates than what is actually available (Bouis & Haddad 1992). In Table 7, the estimates for available rice and roti have been revised based on this additional information and distributed according to the relative proportions from the original survey data. Again, the figures for rice have been multiplied by a conversion factor of 2.32 (Banjong, Viriyapanich & Chitchang 1995) to obtain the equivalent weight for white rice in cooked form. No conversion factor is available for equivalent weight of cooked roti made from uncooked flour, however the moisture content of roti is low and it is assumed that conversion factor would be close to unity.

Table 6 - Daily food consumption of a typical Humla family (RIDS-Nepal study).

Family member	January (g/day)			February (g/day)			March (g/day)		
	Rice	Roti	Daal	Rice	Roti	Daal	Rice	Roti	Daal
Adult male	371	180	65	348	170	55	325	160	45
Adult female	116	200	30	116	180	25	116	150	20
Child 7-9	209	60	65	220	55	55	232	50	45
Child 4-6	139	50	45	128	45	40	116	40	37
Child 1-3	139	60	30	128	55	25	162	50	20
Family total	974	550	235	940	505	200	951	450	167

Table 7 - Revised daily food consumption of a typical Humla family.

Family member	January (g/day)			February (g/day)			March (g/day)		
	Rice	Roti	Daal	Rice	Roti	Daal	Rice	Roti	Daal
Adult male	631	333	65	608	343	55	563	362	45
Adult female	197	371	30	203	363	25	201	340	20
Child 7-9	355	111	65	385	111	55	402	113	45
Child 4-6	237	93	45	223	91	40	201	91	37
Child 1-3	237	111	30	223	111	25	281	113	20
Family total	1657	1019	235	1642	1019	200	1647	1019	167

These consumption figures were then combined with nutrient data to determine the current nutritional intake of a typical poor family in Humla. Figures from the neighbouring district of Mugu show that millet accounts for 45% of the total grain production, which was supported by observations in Humla. Combined with the fact that millet is harvested in the mountains just prior to winter (WFP / NDRI 2010, p. 11) it was assumed that the roti was made primarily from millet in winter. It was also assumed that the daal was made from kidney beans (*simi*), as this is typical in mountain areas (Adhikari 2008, p. 198).

The nutrient content of the available foods is shown in Table 8. According to Ruel (2002), there is no standard list of nutrients to define nutrient adequacy. Based on the recommendations of Emeriau (2006) and the RIDS-Nepal 2007 study, the nutrient analysis focuses on protein, iron, vitamin A and C and zinc levels in the food consumed (Table 8). As mentioned in Chapter 2, vitamin A, iron and protein deficiencies are already recognized as public health problems in Nepal (MOHP 2007). Iron, vitamin A, zinc and vitamin C are important for the immune response (Beard 2001; Prinz et al. 1977; Semba 2001; Shankar & Prasad 1998; Wapnir 2000), which is particularly relevant in Humla where there is an increased risk of infectious diseases from poor sanitation and water quality. Although vitamin A and iron can be stored in the body for a number of months, it is desirable to have a regular intake since national figures related to vitamin A deficiencies indicate that little storage is occurring (MOHP 2007). Vitamin C is also important for uptake of non-heme iron (from vegetables) (Hallberg, Brune & Rossander 1989; Monsen 1988).

Due to the lack of soil nutrient data, it is not possible to determine the exact nutrient content of foods grown in the area and the nutrient values in Table 8 should therefore be considered as a starting point only. Andersen (2007) found that zinc deficiency was widespread in mountain soils in Nepal and stated that it was known to effect zinc levels in crops such as rice. Therefore it is assumed that the zinc levels in grain crops in Humla would be at the lower end of the range of values found in literature.

Table 8 - Nutritional content of food consumed per 100 g (Duke 1992; USDA-ARS 2008).

<i>Food type</i>	<i>Protein (g)</i>	<i>Iron (mg)</i>	<i>Zinc (mg)</i>	<i>Vit. A (µg)</i>	<i>Vit. C (mg)</i>	<i>Energy (kcal)</i>
Rice (cooked)	2.38	1.49	0.42	0.0	0.0	130
Millet (dried, baked)	11.0	3.0	2.0	0.0	0.0	378
Kidney beans (dried, cooked)	2.1	6.4	2.0	0.0	0.0	271

By combining the figures from Table 7 and Table 8, the estimates for nutritional intake for each month could be determined and are shown in Table 9.

Table 9 - Daily estimated nutritional intake of a typical Humla family over winter.

<i>Family member</i>		<i>Protein (g)</i>	<i>Iron (mg)</i>	<i>Zinc (mg)</i>	<i>Vit. A (µg)</i>	<i>Vit. C (mg)</i>	<i>Energy (kcal)</i>
January	Adult male	53	24	11	0	0	2257
	Adult Female	46	16	9	0	0	1738
	Child 7-9	22	13	5	0	0	1058
	Child 4-6	17	9	4	0	0	780
	Child 1-3	18	9	4	0	0	809
	Family total	156	70	32	0	0	6643
February	Adult male	53	23	11	0	0	2236
	Adult Female	45	16	9	0	0	1704
	Child 7-9	23	13	5	0	0	1069
	Child 4-6	16	9	4	0	0	742
	Child 1-3	18	8	4	0	0	777
	Family total	155	68	31	0	0	6529
March	Adult male	54	22	11	0	0	2223
	Adult Female	43	14	8	0	0	1599
	Child 7-9	23	12	5	0	0	1072
	Child 4-6	16	8	3	0	0	704
	Child 1-3	20	9	4	0	0	848
	Family total	155	66	31	0	0	6446

To determine the nutritional shortfall, these values were then compared with recommended vitamin and mineral intakes (WHO/FAO 1998) and energy and protein requirements (FAO/WHO/UNU 1991) determined by the World Health Organisation (WHO) and Food and Agriculture Organisation (FAO). These values are used worldwide, and do not necessarily represent the specific needs of Humla people. They are being used however in the absence of local data and are considered as a starting point only.

Since the local diets are largely vegetarian, the recommended nutrient intakes (RNI) levels used for iron and zinc have been based on the assumption of low bio-availability, meaning that only 5 - 10% of the nutrient content of the food can be absorbed in the body respectively. In the case of iron, they are based on the 95th percentile of the absorbed iron requirements. For zinc, the RNIs have been derived from the estimates of average individual dietary requirements (based on zinc absorption studies) with the addition of 50% (two standard deviations). For vitamin C, the RNIs refer to the amount required to saturate body tissues in 97.5% of the population. The RNI requirements for the breast-feeding baby have been incorporated with those of the mother by assuming she is lactating (WHO/FAO 1998).

The energy and protein requirements have been modified from the general figures published by the FAO, WHO and UNU (1991) to incorporate country specific figures according to the country profile of food security indicators for Nepal (FAO 2008). This profile states the average dietary energy requirements (ADER) are 2160 kcal/day per person. This is slightly higher than the ADER of the general figures (2106 kcal/day) from the FAO, WHO and UNU publication. For the purposes of this research, the energy requirements have been increased proportionally to reflect the country specific figures. This was done by determining the ratio between the general figure for each family member and the average of the general figures, and then multiplying the country specific ADER by those ratios. The energy results are shown in Table 10 and the overall RNI figures for all nutrients for each family member are shown in Table 11.

Table 10 – Modification to energy RNI according to minimum energy requirements.

<i>Family member</i>	<i>General energy RNI (kcal/day)</i>	<i>Ratio RNI/ Average RNI</i>	<i>Country specific RNI (kcal/day)</i>
Adult male	2875	1.36	2949
Adult Female (lactating)	2775	1.32	2846
Child 7-9	1950	0.92	2000
Child 4-6	1690	0.80	1733
Child 1-3	1240	0.59	1272
Average	2106	-	2160

Table 11 - Recommended daily vitamin, mineral, protein and energy intakes.

<i>Family member</i>	<i>Protein (g)</i>	<i>Iron (mg)</i>	<i>Zinc (mg)</i>	<i>Vit. A (µg)</i>	<i>Vit. C (mg)</i>	<i>Energy (kcal)</i>
Adult Male	60	27.4	14.0	600	45	2949
Adult Female (lactating)	50	30.0	17.5	850	70	2846
Child 7-9	41	17.8	11.2	500	35	2000
Child 4-6	30	12.6	9.6	450	30	1733
Child 1-3	22	11.6	8.3	400	30	1272
Family total	203	99.4	60.6	2800	210	10800

The comparison of the results from Table 9 and Table 11 in Figure 25 show the local diet over the winter period is seriously lacking in vitamins and minerals, particularly vitamin A and vitamin C. A lack of bulk food is also indicated by the low protein and energy levels. This indicates that food consumption needs to be increased substantially and diversified.

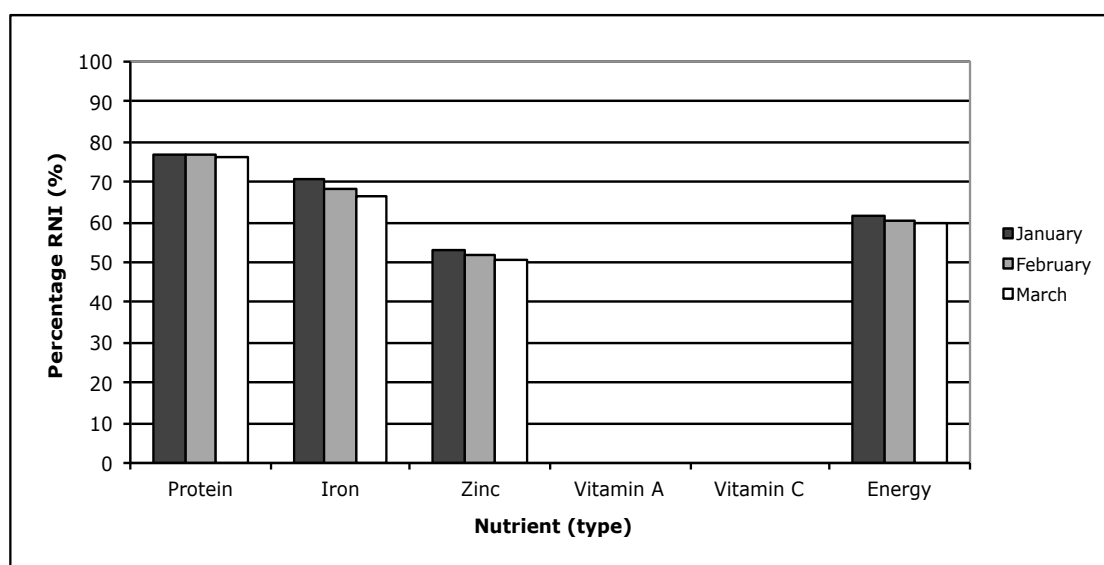


Figure 25 - Daily nutritional intake for a Humla family in winter.

Since the values for current daily nutritional intakes for each winter month are the same or similar for the nutrients included in the analysis, average values have been assumed when considering the contribution from the greenhouse and solar dryer in later sections. The average values and percentages of RNI (i.e. NAR) are listed below in Table 12. The MAR for the selected nutrients for a family is 42.9 %.

Table 12 - Current average daily levels of nutrients for an entire family over winter.

	Protein (g)	Iron (mg)	Zinc (mg)	Vit. A (μ g)	Vit. C (mg)	Energy (kcal)
Available amount for family	156	68	31	0	0	6539
% RNI	77	68	52	0	0	61

These values form the baseline for nutritional adequacy. The gap between these values and the RNI levels indicate how much needs to be improved and form the nutritional criteria.

5.2 Contribution from Greenhouse

In this section, the contribution from the solar greenhouse is explored. The nutritional contribution from the greenhouse has been estimated based on yield data in Humla and other areas, and assumptions regarding losses during cooking

and processing. A linear programming model was developed to incorporate the various parameters relating to nutrient content and yields of different crops, along with local constraints related to growing area and portion size. The aim of the modeling process was to explore the combination of crops that would give the best overall nutritional improvement, which is reflected in the objective function.

5.2.1 Crop selection, nutrient and yield parameters

Based on information from projects in Ladakh, one potential greenhouse crop was assumed to be spinach. This crop is considered to be appropriate because it is already grown and eaten in Humla and because it is high in vitamin A, vitamin C, iron and contains zinc. Other vegetables that are already grown and eaten in Humla, and can be grown in similar conditions to spinach (Bartok et al. 1982), include carrots, swiss chard, cauliflower and potatoes. These crops were also chosen because their nutrients complement those available in spinach.

Cauliflower is a vegetable that is low in vitamin A, high in vitamin C with similar energy levels to spinach. Swiss chard has lower vitamin A levels, higher vitamin C levels, while carrot and potato have higher energy levels. Carrot also has particularly high vitamin A levels.

To determine the effective contribution of the greenhouse crop, possible nutrient reductions due to soil quality and during cooking were considered. Although comprehensive soil data for Humla is not available, some assumptions have been made based on data from other mountain areas. Measurements made by Varadachari et al. (2009) of vitamin C, iron and zinc in green leafy crops in Pithoragarh in India show that levels in fresh form are at the lower end of the range of those found in literature. Therefore this has been assumed to be the case for vegetables grown in Humla. No specific information has been found about the effect of soil quality on Vitamin A levels in fresh vegetables, so a value has been chosen in the middle of the range found in literature.

Although it would be preferable for some crops to be eaten fresh to conserve nutrient content, normal preparation procedures have been assumed, which, in some cases, reduce the nutrient levels in vegetables even further. The procedures do, however, make the food safer and reduce the health risks associated with uncooked food and contaminated water. Most vegetables are well cooked and served as part of a curry that accompanies the daal and rice or roti. The exception is carrot, which is generally eaten raw. According to Singal and

Kulkarni (1998), the vitamin A levels in fresh spinach would be reduced by up to 25% and vitamin C levels by at least 70% when boiled. Although protein structures in food are altered by cooking, their levels remain the same and virtually all mineral levels, including iron and zinc, are unaffected (USDA-ARS 2008). The overall estimated nutrient contribution of each crop is listed below in Table 13. It must be noted that since issues related to nutrient uptake have not been considered because they are difficult to quantify, these values are only an estimate.

Table 13 - Nutrient content of vegetables per 100 g (Duke 1992; USDA-ARS 2008).

Food Type	Protein (g)	Iron (mg)	Zinc (mg)	Vit. A ($\mu\text{g RE}$)	Vit. C (mg)	Energy (kcal)
Boiled spinach	2.97	3.57	0.76	524	9.8	23
Boiled cauliflower	1.84	0.32	0.17	1.0	44.3	23
Raw carrot	0.93	0.30	0.24	835	5.9	41
Boiled Swiss chard	1.88	2.26	0.33	306	18.0	20
Boiled potato	2.86	6.07	0.44	0.00	5.2	51

The yield data for each crop was estimated based on the amount produced and the growing time required, taking into account that some crops grow faster than others. The greenhouse yields for spinach were estimated from data published by Stauffer et al. (2004) in relation to greenhouses in Ladakh. Average green leafy vegetable production is 50 kg per month for a greenhouse with a growing area of 25 m². This results in a yield of 2 kg/ m²/month. According to Subedi (2003), 3.4 Mt/ha (3.4 kg/m²) of potatoes are produced in the mountains of Nepal per year. Considering that the growing season is seven months long from April to October, this equates to 0.49 kg/m² /month. The yields for Swiss chard were assumed to be the same as that of spinach, since it was another green leafy vegetable, while the yields for cauliflower and carrots were assumed to be 0.67 kg/m²/month and 3.4 kg/m²/month respectively, based on field harvest data (McClurg, 2001; McCollum et al, 1986) and the number of possible harvests from January to March. These were general figures not specific to Nepal or high altitude areas, meaning that they still would need to be verified with experimental data.

5.2.2 Linear programming model – greenhouse only

The nutritional and yield data outlined in Section 5.2.1 have been used in a linear programming model to determine the contribution of the greenhouse to improvements in the overall nutritional status of an average family. This is a method that has been widely used in agricultural and human nutrition applications, from farm planning to the design of palatable diets for populations (Dent, Harrison & Woodford 1986; Foytik 1981).

A linear programming problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints, which may be equalities or inequalities. The general form of a linear programming problem is shown below (Dent, Harrison & Woodford 1986):

$$\min/\max_x f^T x \text{ such that } \begin{cases} A \cdot x \leq b \\ A_{eq} \cdot x = b_{eq} \\ x \geq 0 \end{cases} \quad \text{Eq. 1}$$

where $\mathbf{x}$ is the solution vector, $\mathbf{f}$ is the linear objection function vector, $\mathbf{A}$ is the matrix for linear inequality constraints, $\mathbf{b}$ is the vector for linear inequality constraints, $\mathbf{A}_{eq}$ is the matrix for linear equality constraints and $\mathbf{b}_{eq}$ is the vector for linear equality constraints.

In this case, no equality constraints were applicable, so the expanded form of Equation 1 is as follows:

$$f^T x = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \begin{bmatrix} x_1 & x_2 & \dots & x_n \end{bmatrix} = f_1 x_1 + f_2 x_2 + \dots + f_n x_n$$

subject to:

$$A \cdot x \leq b \Rightarrow \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 & x_2 & \dots & x_n \end{bmatrix} \leq \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix} \Rightarrow \begin{array}{ccccccc} a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n & \leq & b_1 \\ a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n & \leq & b_2 \\ \vdots & & \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n & \leq & b_m \end{array}$$

Darmon et al. (2002) used linear programming to select diets for pre-school children in rural Malawi based on local foods that satisfied a set of nutritional constraints, while minimizing the total energy content of the diet. In this particular case, energy requirements were already being met, but other micronutrient requirements were not. It was not clear whether the micronutrient deficiencies were caused by the lack of locally available nutrient dense food or by the fact that bulk staple foods took prominence in the diet at the expense of diverse nutrient dense foods. The study investigated whether the micronutrient deficiencies could be addressed with locally available foods. Additional constraints on daily intakes of foods and food groups were also introduced to ensure that the diets were compatible with local food patterns. Linear programming was found to be a useful method to assist in the formulation of nutritional recommendations based on data from food consumption surveys.

For the purpose of this research, a similar process was used to determine which combination of crops would provide the best overall nutritional improvement and how much of the growing area inside the greenhouse should be allocated to each crop, represented by the solution vector $\mathbf{x}$. In this case however, energy is one of the nutrients in deficit. The objective function was the sum of the percentage of the RNI met for each selected nutrient, each of which was a function of the growing area, x , and overall nutritional content for each crop:

$$f^T \mathbf{x} = f_{spinach} x_{spinach} + f_{cauli-flower} x_{cauli-flower} + f_{swiss-chard} x_{swiss-chard} + f_{carrot} x_{carrot} + f_{potato} x_{potato} \quad \text{Eq. 2}$$

where each component of the f vector was determined from the nutrient and yield data according to the general formula:

$$f_{crop} = \text{daily yield (g / m}^2\text{)}_{crop} \left(\sum \frac{\text{nutrient content of each nutrient per gram of crop (g / g)}}{\text{RNI of each nutrient (g)}} \right) \times 100 \quad \text{Eq. 3}$$

For example, the equation for the coefficient for the nutritional contribution of spinach, $f_{spinach}$, is:

$$f_{spinach} = \text{yield}_{spinach} \left(\frac{\text{protein}_{spinach}(\text{g / g})}{\text{protein}_{RNI}(\text{g})} + \frac{\text{iron}_{spinach}(\text{g / g})}{\text{iron}_{RNI}(\text{g})} + \frac{\text{vitamin A}_{spinach}(\text{g / g})}{\text{vitamin A}_{RNI}(\text{g})} + \frac{\text{vitamin C}_{spinach}(\text{g / g})}{\text{vitamin C}_{RNI}(\text{g})} + \frac{\text{zinc}_{spinach}(\text{g / g})}{\text{zinc}_{RNI}(\text{g})} + \frac{\text{energy}_{spinach}(\text{g / g})}{\text{energy}_{RNI}(\text{g})} \right) \times 100 \quad \text{Eq. 4}$$

The percentage of the RNI for each nutrient met from the combination of all crops could then be added to the percentage of the RNI already met in the existing diet to determine the NAR and MAR for the family.

Constraints were placed on growing area and realistic portion size in the model. The sum of growing area for each crop had to be less than or equal to the total area of the greenhouse. Therefore:

$$50 \geq x_{spinach} + x_{cauliflower} + x_{swiss chard} + x_{carrot} + x_{potato} \quad \text{Eq. 5}$$

or

$$50 \geq a_{11}x_{spinach} + a_{12}x_{cauliflower} + a_{13}x_{swiss chard} + a_{14}x_{carrot} + a_{15}x_{potato}$$

where a_{11} , a_{12} , a_{13} , a_{14} and a_{15} are all equal to one, and x is the solution vector which gives the recommended growing area allocation in the greenhouse.

Total growing area is a parameter within the linear programming model, however to explore the benefits of different sized greenhouses, it was varied for successive runs of the model. The limits on growing area as a variable depend on a number of factors. Rozis and Guinebault (1996) state that 12 m² of growing area is suitable for the needs of a family in Ladakh and Stauffer et al. (2004) state that a 50 m² greenhouse, with 25 m² of effective growing area, is sufficient for a family's needs along with excess for income generation. Gautam et al. (2006) state that kitchen gardens in Nepal range from 17 – 500 m². Based on fieldwork observations, the land available for kitchen gardens in villages in mountainous areas is significantly less than this upper limit suggests. Since it is considered preferable to have the greenhouse close to the family's dwelling to reduce time and effort required for maintenance and harvesting, a constraint of 50 m², similar to the maximum size of the greenhouses in Ladakh, has been placed on the growing area in the greenhouse. To explore the benefits of different sized greenhouses, the linear programming model was run with total area constraints from 0 – 50 m².

The portion size for each vegetable was determined based on palatability and relative quantities in a typical meal. The greenhouse crops form part of the curry (excluding carrot which is eaten raw) that is generally made up of any vegetables that are available. It was observed during fieldwork that the quantity of curry is

normally less than the amount of rice but more than the amount of daal. Based on figures from Table 7, the average total amount of rice eaten per family member over the winter period (excluding the breast-feeding baby) is 275 grams per day and the average amount of daal eaten per day is 34 grams. Therefore, a range of 34 – 275 grams has been placed on the total amount of vegetables each day. This equates to a daily constraint of between 200 -1375 grams per day for the whole family. Therefore:

$$1375 \geq a_{21}x_{spinach} + a_{22}x_{cauliflower} + a_{23}x_{swiss\ chard} + a_{24}x_{carrot} + a_{25}x_{potato} \quad \text{Eq. 6}$$

where a_{21} , a_{22} , a_{23} and a_{25} represent the daily yield of each crop per square metre in grams and x is the solution vector, which gives the recommended growing area distribution in the greenhouse. Carrot was excluded from this constraint as it is normally eaten raw and not part of the vegetable curry, therefore a_{24} is equal to zero. An additional constraint was added to the portion size of raw carrot, since it is usually eaten as a side dish and because it is preferred to have cooked food as the majority of each meal. A constraint of 200 grams per person eating solid food per day has therefore been imposed on the quantity of raw carrot. This equates to 1000 grams per family per day:

$$1000 \geq a_{31}x_{spinach} + a_{32}x_{cauliflower} + a_{33}x_{swiss\ chard} + a_{34}x_{carrot} + a_{35}x_{potato} \quad \text{Eq. 7}$$

where a_{34} represents the daily yield of carrot per square metre per day and a_{31} , a_{32} , a_{33} and a_{35} are all equal to zero. Again, x is the solution vector which gives the recommended growing area distribution in the greenhouse.

Although high levels of vitamin A can be unsafe, toxicity is only attributed to pre-formed vitamin A (retinol) from animal products, not carotenoids found in vegetables (Ross 1999). Since the Humla diet is largely vegetarian, initially a restriction was not imposed on Vitamin A levels.

The f and b vectors, and A matrix for the linear programming problem are shown below. The value for each crop in the f vector has been calculated with Equation 3 (with a more detailed example for spinach shown in Equation 4). The A and b matrices are formed from the three constraint equations mentioned previously

(Equations 5, 6, & 7). The values in the second and third lines of the A matrix have been initially derived from literature (see Section 5.2.1 and Table 13 for references), however they will be updated once experimental values for crop yield have been determined (Chapter 6).

$$f = \begin{bmatrix} 19.5 \\ 5.1 \\ 15.6 \\ 38.7 \\ 1.9 \end{bmatrix} \begin{array}{l} \leftarrow \text{nutrient content of spinach per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of cauliflower per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of swiss chard per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of carrot per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of potato per m}^2 \text{ growing area.} \end{array}$$

$$b = \begin{bmatrix} 50 \\ 1375 \\ 1000 \end{bmatrix} \quad A = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 66.7 & 22.3 & 66.7 & 0 & 17.0 \\ 0 & 0 & 0 & 113.3 & 0 \end{bmatrix} \begin{array}{l} \leftarrow \text{area constraint} \\ \leftarrow \text{portion constraint - curry} \\ \leftarrow \text{portion constraint - carrot} \end{array}$$

The values of the coefficients for each crop in the f vector already give an indication as to which crops will contribute the most to increasing the objective function and potentially dominate the results. Carrot has the highest coefficient, followed by spinach and swiss chard. Cauliflower has a value a third the size of swiss chard. Potato has a coefficient that is an order of magnitude lower than carrot, spinach and swiss chard, and smaller than the coefficient of carrot by a factor of 20. This means that 20 m² of growing area planted with potatoes would contribute the same amount to the objective function as 1 m² planted with carrot.

5.2.3 Multivariate analysis results for greenhouse only

The linear programming model was run separately for different values of available growing area. Table 14 shows the NARs and MARs that result from the combination of existing food and additional food from greenhouse for the whole family for increasing greenhouse size (indicated by "Total growing area" in Column 1). The NARs above 100% have been truncated to 100% when calculating the MAR for each increment of growing area. Nutrient levels are significantly improved for protein, iron, vitamin A and vitamin C, but only slightly improved for zinc and energy.

Table 14 – Nutrient levels from combination of existing food (rice, daal and roti) and greenhouse produce (carrot and spinach) for different total growing greenhouse areas.

Total Growing Area (m ²)	Nutrient adequacy ratios (% RNI)						Mean nutrient adequacy ratio (%)
	Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy	
0	76.7	68.4	0.0	0.0	51.7	60.6	42.9
10	82.4	74.2	312.9	31.8	56.1	64.5	68.2
15	87.3	86.2	375.3	47.3	58.3	65.2	74.1
20	92.1	98.2	437.7	62.9	60.5	65.9	79.9
25	97.0	110.2	500.0	78.4	62.7	66.6	84.1
30	101.3	120.8	555.5	92.3	64.7	67.3	87.4
35	101.3	120.8	555.5	92.3	64.7	67.3	87.4
40	101.3	120.8	555.5	92.3	64.7	67.3	87.4
45	101.3	120.8	555.5	92.3	64.7	67.3	87.4
50	101.3	120.8	555.5	92.3	64.7	67.3	87.4

Note: These nutrient level represent the combination of existing food and the greenhouse contribution. Therefore "0" growing area refers to the current nutritional status as defined in Section 5.1.

In Figure 26, the results for the solution vector for each iteration are shown. Only carrot and spinach have been allocated growing area in the greenhouse, which is to be expected based on their high nutrient content and high coefficient values in the objective function vector, f . When the total growing area reaches 30m², it can be seen that the utilized growing area and nutrient levels plateau, even though the available growing area increases. This suggests that a constraint other than the available growing area is limiting crop production. In Figure 27 it can be seen that the portion constraints on both carrot and spinach (Eq. 6 & 7) are the limiting factors. These were put in place to ensure that the proportion of raw food to cooked food and the proportion of vegetables to rice and daal were palatable.

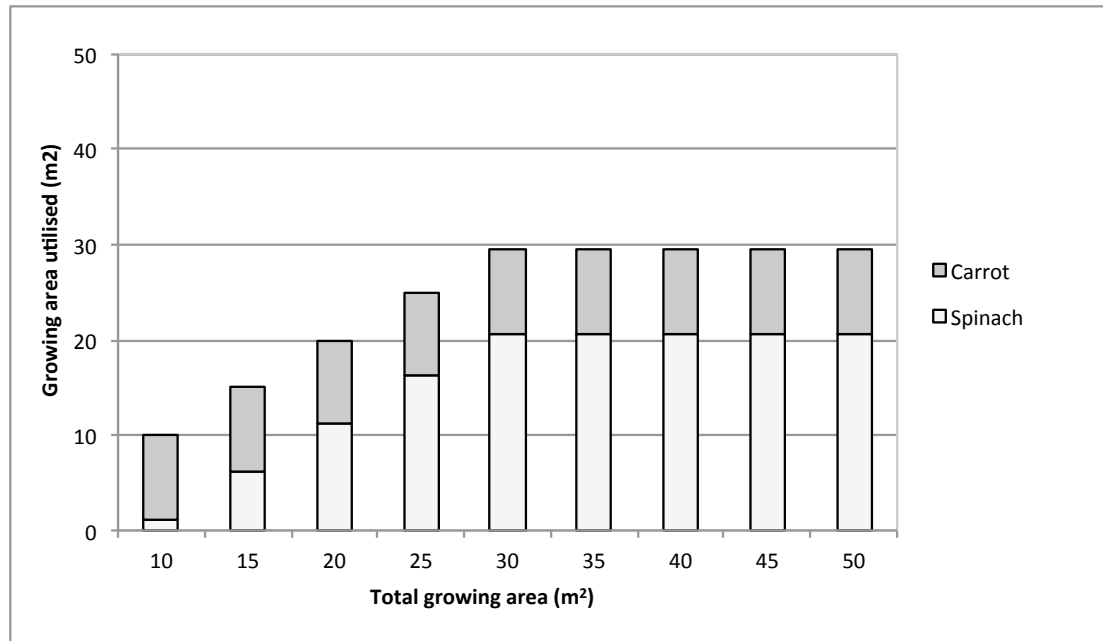


Figure 26 – Growing area per crop as total growing area increases under growing area and portion size constraints.

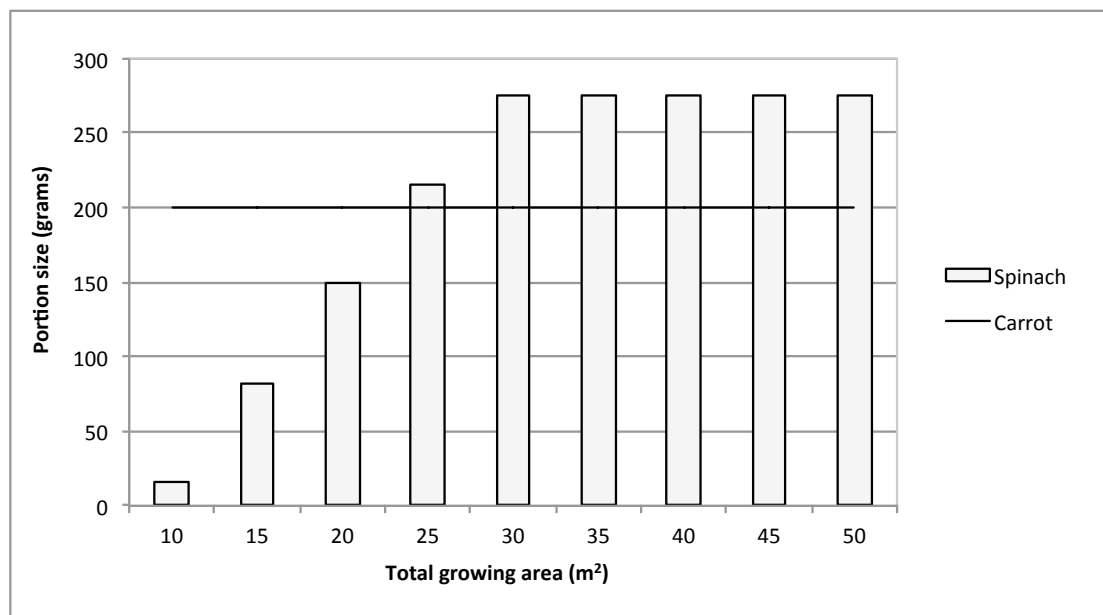


Figure 27 – Variation of portion sizes as total growing area increases under combination of growing area and portion size constraints.

This result, however, does not provide much diversity of ingredients for the vegetable curry, which would be nutritious but made from spinach only. Vitamin A levels dominate at the expense of other vitamins and minerals. This is a particularly a problem with the NAR for vitamin C which does not reach 100%, even as growing area increases. Higher levels of vitamin C are preferable because

it is the nutrient most susceptible to losses during cooking and processing and also because it is important to aid iron absorption.

In an attempt to improve diversity and overall nutrition improvement, a weighted restriction was placed on the vitamin A level terms in the objective function. An iterative process was used. As the total growing area was increased, a condition was introduced that reduced the vitamin A coefficients of the objective function by a factor of ten for the next iteration if the total vitamin A levels of the previous iteration were more than 100% of the RNI. This factor was chosen because the vitamin A levels in the previous results were an order of magnitude higher than the other nutrient levels (see Table 14. Each term in the objective function vector was modified by adding the weighting factor in front of the vitamin A component of each objective function vector coefficient (example shown for spinach):

Without weighting (Eq. 4 shown previously in Section 5.2.2):

$$f_{spinach} = yield_{spinach} \left(\frac{protein_{spinach}(g/g)}{protein_{RNI}(g)} + \frac{iron_{spinach}(g/g)}{iron_{RNI}(g)} + \frac{vitamin A_{spinach}(g/g)}{vitamin A_{RNI}(g)} + \frac{vitamin C_{spinach}(g/g)}{vitamin C_{RNI}(g)} + \frac{zinc_{spinach}(g/g)}{zinc_{RNI}(g)} + \frac{energy_{spinach}(g/g)}{energy_{RNI}(g)} \right) \times 100$$

With weighting:

$$f_{spinach} = yield_{spinach} \left(\frac{protein_{spinach}(g/g)}{protein_{RNI}(g)} + \frac{iron_{spinach}(g/g)}{iron_{RNI}(g)} + w \left[\frac{vitamin A_{spinach}(g/g)}{vitamin A_{RNI}(g)} \right] + \frac{vitamin C_{spinach}(g/g)}{vitamin C_{RNI}(g)} + \frac{zinc_{spinach}(g/g)}{zinc_{RNI}(g)} + \frac{energy_{spinach}(g/g)}{energy_{RNI}(g)} \right) \times 100 \quad \text{Eq. 8}$$

where w is equal to one if the total amount of vitamin A from the previous iteration is less than 100% of the RNI, or equal to 0.1 if the total amount of vitamin A is more than 100% of the RNI.

The results with the modified objective function are shown in Table 15, Figure 28 and Figure 29. Reducing the contribution of vitamin A levels by a factor of ten and reducing their dominance in the objective function resulted in swiss chard replacing spinach in growing area distribution (Figure 28) and as the main ingredient for the vegetable curry (Figure 29). This is due to swiss chard having moderately lower levels than spinach for most of the vitamins and minerals but a

higher amount of vitamin C. As a result, overall protein and iron levels are reduced while vitamin C levels are increased.

In Table 15 it can be seen that the NAR for iron, vitamin A and C are above 100% when the greenhouse area is 25 m², which is an improvement on the previous results. According to Figure 28 and Figure 29 though, the distribution of crops in the greenhouse is similar with carrot and swiss chard only, with swiss chard being the only ingredient in the vegetable curry. Diversity in ingredients doesn't improve until the growing area is 30 m² or more and cauliflower features in the results. The addition of cauliflower improves diversity and palatability, but does not improve nutrition overall. In Table 15 it can be seen that the NAR for protein, iron and vitamin A and zinc peak at a growing area of 30 m². The MAR does not change significantly, which doesn't reflect the improvement in the NARs.

Table 15 – Nutrient levels for combination of existing food (rice, daal and roti) and greenhouse produce (carrot, swiss chard, and in some cases cauliflower) for different total growing areas with weighting on vitamin A levels.

Total Growing Area (m ²)	Nutrient adequacy ratios (% RNI)						Mean nutrient adequacy ratio (%)
	Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy	
0	76.7	68.4	0.0	0.0	51.7	60.5	42.9
5	79.1	74.5	29.1	22.9	52.6	61.0	53.2
10	82.8	83.6	72.9	57.1	54.8	61.8	68.8
15	85.3	89.6	102.0	80.0	56.3	62.3	78.9
20	89.0	98.7	145.7	114.3	58.5	63.0	84.9
25	91.1	100.8	264.3	128.6	60.3	64.5	86.0
30	94.0	102.3	446.5	148.3	62.7	66.9	87.3
35	93.9	99.7	431.8	165.1	62.4	66.9	87.2
40	93.9	95.8	409.8	190.3	61.9	67.0	86.4
45	93.9	93.2	395.1	207.2	61.5	67.0	85.9
50	93.8	90.5	380.4	224.0	61.2	67.1	85.4

The portion constraint still affects the results, however unlike the previous example without the constraint in Vitamin A, the growing area is always fully utilized. The vitamin A constraint allows crops containing high amounts of other nutrients (cauliflower is high in vitamin C) to have greater prominence in the objective function and therefore have growing area allocated to them. This doesn't increase the value of the MAR, but does result in a better spread of NAR results and a more palatable combination of crops.

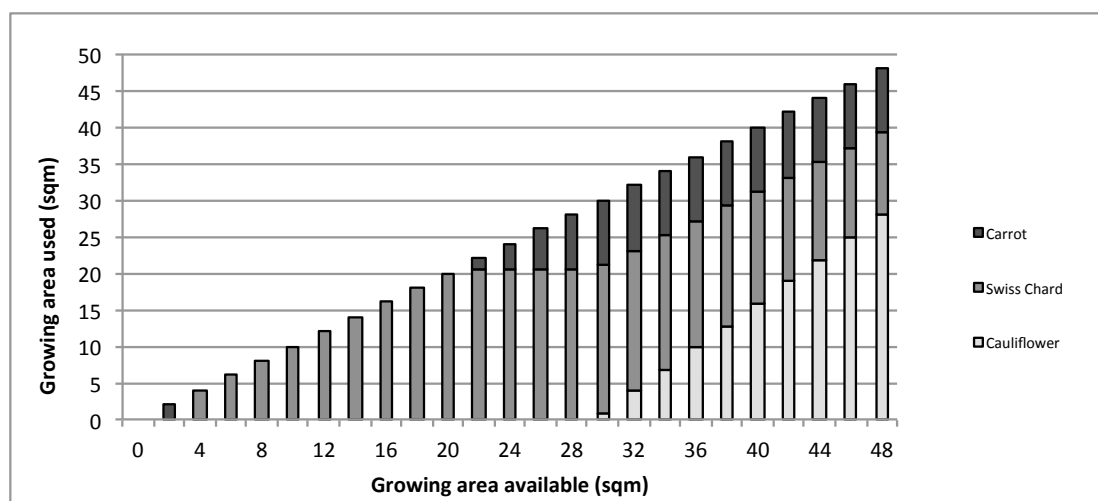


Figure 28– Growing area per crop with weighting on vitamin A levels and under combination of growing area and portion constraints.

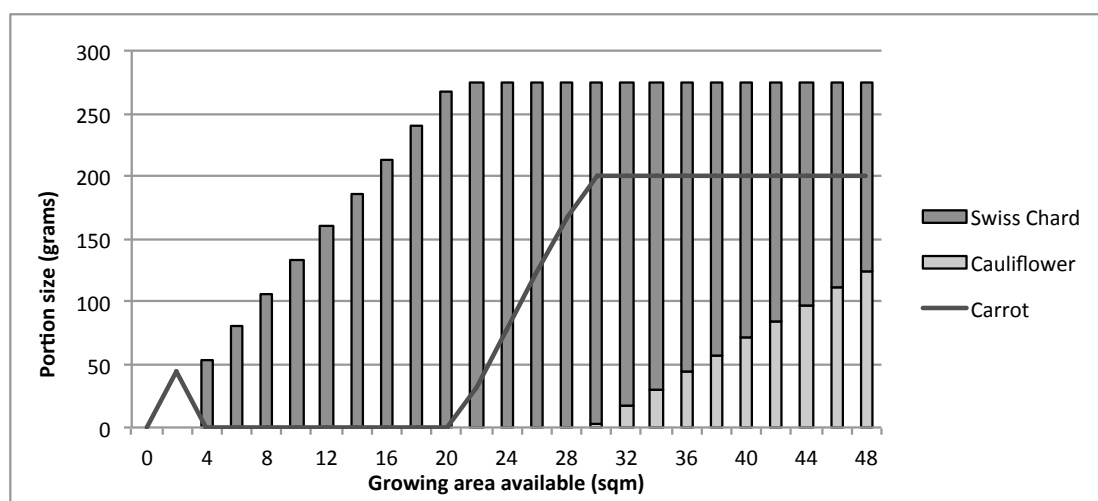


Figure 29 – Daily portion sizes per person for different crops and total vegetable curry portion as growing area increases with weighting on vitamin A content and under growing area and portion constraints.

Including greenhouse produce in the diet addresses vitamin A, vitamin C and partially addresses iron deficiencies. But no significant increase in energy, zinc or protein levels is apparent. One clear result from both analyses is that potatoes do not contribute enough to improving overall nutrition to have been allocated any growing area in the greenhouse. Potatoes were included in the model since they have high energy content, however this result indicates that the potato yield per square metre is not high enough to contribute to improving energy levels, compared to the density of other nutrients in other crops.

In general it seems that locally available vegetable crops that are high in energy and can be grown in a greenhouse, such as corn, are not high in other specified nutrients (Table 16). Based on general field data from Nepal, they also have low yields per square metre. The exception to this is carrot, which is high in both energy and micronutrients, and has a potentially high yield (although this needs to be verified with experimentation). Carrot, however, is restricted by the raw portion constraint and is not generally eaten in sufficient quantities to address energy deficiencies.

Table 16 - Nutrient content of vegetables per 100 g (Duke 1992; USDA-ARS 2008) and yield per square metre per month ((Fang et al. 2007; NARC 2007) of local vegetables high in energy.

Food Type	Protein (g)	Iron (mg)	Zinc (mg)	Vit. A (µg RE)	Vit. C (mg)	Energy (kcal)	Yield (kg/m ² /month)
Raw carrot	0.93	0.30	0.24	835	5.9	41	3.4
Boiled potato	2.86	6.07	0.44	0.00	5.2	51	0.49
Boiled corn	3.41	0.45	0.62	13	5.5	96	0.28*

* The yield per square metre per month for corn has been calculated based on Nepal country figures for corn production of 2 MT/ha (NARC 2007) and total growing season of seven months in the mountains (Fang et al. 2007).

These figures suggest that it is not feasible to address energy deficiencies with greenhouse produce if the aim is to improve nutrition overall within the portion constraint for raw food and while adhering to the “appropriateness” requirement for local crops. Other crops do exist that have higher overall nutrients, such as mashua and yacon tuber crops cultivated in the mountains or Peru (Alfredo et al. 2003; Hermann & Heller 1997) however these are not currently grown in Humla and it is outside the scope of this research project to determine if they would be suitable.

5.3 Contribution from Solar Dryer

In the previous section, the potential contribution of crops from the greenhouse was found to improve available nutrients considerably. In this section, additional contribution from the solar dryer produce is explored to see if it can address the gaps in the nutritional criteria not addressed by the greenhouse crops, while operating within local requirements. This involves selection of crops with complimentary nutrient levels and modifications to the linear programming model, including extra terms in the objective function and solution vector, and additional constraints.

5.3.1 Crop selection, nutrient and yield parameters

For the solar dryer, apples and chuli, a fruit very similar to an apricot, were initially chosen as the main crops because these are two of the few fruits in surplus during the summer months and also because they complement the greenhouse crop in terms of the nutritional deficiencies identified by having high energy levels (Table 17).

Again, possible nutrient reductions due to processing were considered. During drying, vitamin A is susceptible to oxidation, with levels reduced by up to 40%, but only 10-15% if the crop is blanched beforehand (Salunkhe 1974). Vitamin C is largely destroyed due to exposure to heat and air (Rahman 2008). Protein and virtually all mineral levels, including iron and zinc, are unaffected by heat or air. The overall estimated nutrient contents of dried and reconstituted apples and apricots are listed in Table 17. It is also assumed that the weight of both the apples and the apricots once dried and reconstituted would be the same as the fresh weight.

Table 17- Nutrient content of fruit per 100 g (Duke 1992; USDA-ARS 2008).

<i>Food Type</i>	<i>Protein (g)</i>	<i>Iron (mg)</i>	<i>Zinc (mg)</i>	<i>Vit. A (μg RE)</i>	<i>Vit. C (mg)</i>	<i>Energy (kcal)</i>
Apples (dried, stewed)	0.22	0.33	0.05	1.0	1.0	57
Apricots (dried, stewed)	1.2	0.94	0.14	64	0.3	85

Apricots are harvested in July and August and apples are harvested in September and October. The July / August period is more favourable in terms of available labour time because it does not coincide with the grain harvests in September

and October. However, the average ambient humidity at this time is around 80% since it is the monsoon season (see Chapter 2, Figure 3). Even though apricots have superior nutritional levels compared to apples, they were omitted as a potential drying crop because the conditions in July and August are not considered to be suitable for drying. The possibility of storing the apricots in a cool store underground for drying later in the year was considered. However, it is recommended that stone fruit in general should not be stored before drying for any more than a few days even if adequate storage facilities are available (SARDI 2012).

5.3.2 Linear programming model - greenhouse and solar dryer

The nutritional and yield data for apples were incorporated into the linear programming model and used to determine the contribution of the solar dryer produce to improve the nutritional status of an average family. The solution vector, $\mathbf{x}$, and objective function, $\mathbf{f}$, were extended to incorporate the weight of fruit required each year and the contribution to overall nutrition:

$$F_{obj} = f_{spinach}x_{spinach} + f_{cauliflower}x_{cauliflower} + f_{swiss chard}x_{swiss chard} + f_{carrot}x_{carrot} + f_{potato}x_{potato} + f_{apple}x_{apple} \quad \text{Eq. 9}$$

where:

$$f_{apples} = \left(\frac{protein_{apples}(g/g)}{protein_{RNI}(g)} + \frac{iron_{apples}(g/g)}{iron_{RNI}(g)} + w \left[\frac{vitamin A_{apples}(g/g)}{vitamin A_{RNI}(g)} \right] + \frac{vitamin C_{apples}(g/g)}{vitamin C_{RNI}(g)} + \frac{zinc_{apples}(g/g)}{zinc_{RNI}(g)} + \frac{energy_{apples}(g/g)}{energy_{RNI}(g)} \right) \times 100 \quad \text{Eq. 10}$$

An additional constraint was added to account for available labour time during September and October. It is limited due to the fact that the main grain harvest also occurs at this time. Since it is assumed that the greenhouse and solar dryer will be operated together to improve nutrition, resulting in competing labour allocation, labour time will be added as an additional constraint in the linear programming model. To have fresh crops available in winter in the greenhouse, it is necessary to plant them in September/ October. Likewise, to have dried crops available in winter it is necessary to dry them during this period because it coincides with the apple harvest period.

The labour time available for greenhouse and dryer operation is estimated to be no more than one hour per day, or 60 hours over the entire two months. From observations of existing greenhouses, it is estimated that watering requires one minute per square metre and can be done every second day. From observations of existing solar dryers, inserting and removing trays at the beginning and end of each drying day takes 20 minutes for six kilograms of produce, or approximately three minutes per kilogram. In addition to this, it was observed to take half a day (four hours) to prepare the soil and plant seeds in a 25 m² greenhouse, and one day (8 hours) to harvest 20 kg of apples and 2 hours to prepare 6kg of apples for drying. Apple trees tend not to be close to villages, so some walking is involved in harvesting. Apples also are generally prepared by hand, without mechanized aids. It is acknowledged that these aids could reduce the preparation time, but this has not been incorporated into the preparation time because they are not currently in use. In total, labour time required for the greenhouse is 0.66 hours per square metre of growing area and 4.1 hours per kilogram of solar dryer fresh produce. Over the entire harvest season. the constraint equation in hours is:

$$60 \geq a_{51}x_{spinach} + a_{52}x_{cauliflower} + a_{53}x_{swiss\ chard} + a_{54}x_{carrot} + a_{55}x_{potato} + a_{56}x_{apple} \quad \text{Eq. 11}$$

where the coefficients a_{51} , a_{52} , a_{53} , a_{54} and a_{55} are all equal to 0.66 and a_{56} is equal to 4.1. The extended constraint matrix is shown below. The values for the coefficients in the A and b matrices come from Equations 5, 6, 7 and 11.

$$f = \begin{bmatrix} 19.5 \\ 5.1 \\ 15.6 \\ 38.7 \\ 1.9 \\ 0.17 \end{bmatrix} \begin{array}{l} \leftarrow \text{nutrient content of spinach per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of cauliflower per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of swiss chard per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of carrot per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of potato per m}^2 \text{ growing area.} \\ \leftarrow \text{nutrient content of apple per kg harvested.} \end{array}$$

$$b = \begin{bmatrix} 50 \\ 1375 \\ 1000 \\ 60 \end{bmatrix} \quad A = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 \\ 66.7 & 22.3 & 66.7 & 0 & 17.0 & 0 \\ 0 & 0 & 0 & 113.3 & 0 & 0 \\ 0.66 & 0.66 & 0.66 & 0.66 & 0.66 & 4.1 \end{bmatrix} \begin{array}{l} \leftarrow \text{area constraint} \\ \leftarrow \text{portion constraint (curry)} \\ \leftarrow \text{portion constraint (carrot)} \\ \leftarrow \text{labour constraint} \end{array}$$

5.3.3 Multi-variate analysis results– greenhouse and solar dryer

The results from the linear programming optimization for different values of portion size and greenhouse growing area, this time including the solar dryer crop, are shown below (Figure 30 and Figure 31). The effect of the solar dryer crop alone could not be explored because of the constraint related to labour time, which involves both greenhouse and solar dryer labour. Similar to the results from the greenhouse produce alone, the area designated to potato was again consistently equal to zero, so these results have not been included.

The linear programming model was again tested for different values of greenhouse growing area, as this will affect the constraint on labour time and the amount of solar dryer crops that can be produced. Table 18 shows the NARs for the whole family and the value of the MAR for increasing greenhouse size (indicated by “total growing area” in Column 1). Figure 30 and Figure 31 show the corresponding growing areas and portion sizes for each crop respectively, with the initial total harvest weight for apples included on the right hand axis.

Table 18 – Nutrient levels for combination of existing produce (rice daal and roti), greenhouse produce (carrot, swiss chard, cauliflower) and solar dryer produce (dried apples) for different total growing areas with weighting on vitamin A levels.

Total Growing Area (m ²)	Total Apples (kg)	Nutrient adequacy ratios (NAR) (% RNI)						MAR (%)
		Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy	
0	15	76.8	69.0	0.1	0.8	51.8	61.4	43.8
5	14	79.3	75.0	29.2	23.6	53.2	61.9	53.7
10	13	83.0	84.0	72.9	57.8	55.4	62.5	69.3
15	12	85.4	90.1	102.0	80.7	56.8	63.0	79.3
20	11	89.1	99.1	145.8	114.9	59.0	63.7	85.2
25	11	91.3	101.2	264.4	129.2	60.8	65.2	86.2
30	10	94.1	102.7	446.5	148.8	63.1	67.5	87.5
35	9	94.0	100.0	431.8	165.6	62.8	67.5	87.4
40	8	94.0	96.1	409.8	190.8	62.2	67.5	86.6
45	7	94.0	93.4	395.1	207.6	61.9	67.5	86.1
50	7	93.9	90.8	380.4	224.3	61.5	67.5	85.6

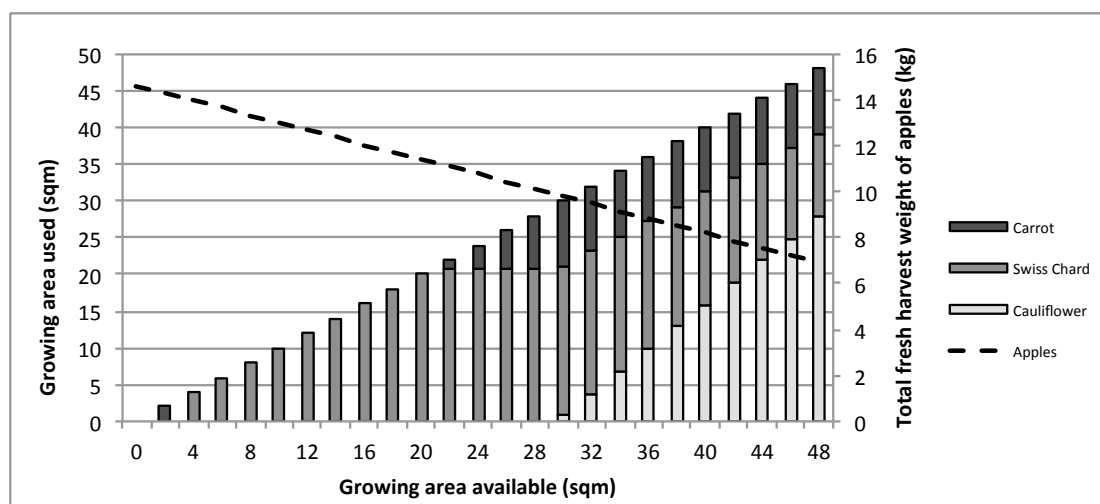


Figure 30 – Growing area per crop and corresponding total harvest amount of apples.

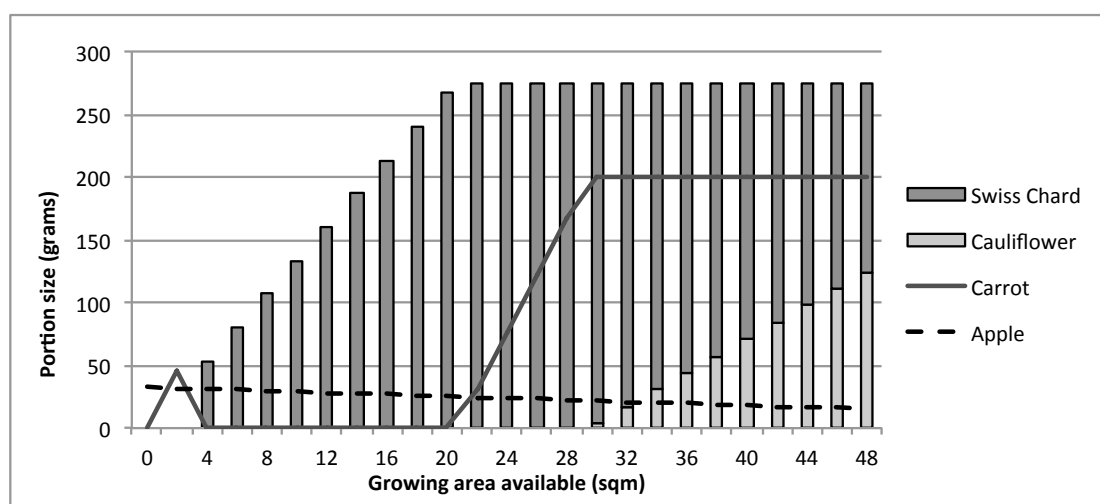


Figure 31 – Daily portion sizes per person for each of the greenhouse and solar dryer crops.

The portion sizes and growing area distribution do not vary much at all compared to the previous greenhouse only scenario. The growing area in the greenhouse is always fully utilized (Figure 30), with the portion constraint coming into effect early on for carrot and later for both carrot and the total amount of vegetables. Figure 31 shows that the daily portion of reconstituted apples is between 31.5 – 33 grams per person, where 33 grams is approximately equal to one third of an apple.

Table 19 shows the increase in NARs (percentage points) with the addition of apples for each increment of greenhouse growing area. It can be seen that the

difference between the scenario with and without the solar dryer contribution is minimal in most cases. This could potentially be explained by the low value for apples in the objective function vector, which is an order of magnitude lower than the values for the greenhouse crops. However, this could be overcome if the harvest amount of apples was of a higher order of magnitude. The results in Table 18 indicate that this is not the case, which shows that another constraint is restricting the amount of apples.

Table 19 – Increase in percentage points of NAR with the addition of apples for different growing areas.

Total Greenhouse Growing Area (m ²)	Total Apples (kg)	Increase in Nutrient adequacy ratio (pp)					
		Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy
0	15	0.2	0.5	0.1	0.8	0.7	0.9
5	14	0.2	0.5	0.1	0.7	0.6	0.8
10	13	0.2	0.5	0.1	0.7	0.6	0.8
15	12	0.1	0.5	0.0	0.7	0.6	0.7
20	11	0.1	0.4	0.0	0.6	0.5	0.7
25	11	0.1	0.4	0.0	0.6	0.5	0.6
30	10	0.1	0.4	0.0	0.5	0.4	0.6
35	9	0.1	0.3	0.0	0.5	0.4	0.5
40	8	0.1	0.3	0.0	0.4	0.4	0.5
45	7	0.1	0.3	0.0	0.4	0.3	0.4
50	7	0.1	0.3	0.0	0.4	0.3	0.4

Figure 32 shows the labour time constraint plotted against increasing greenhouse total available growing area. It is clear that the labour time involved in drying the apples is the main constraint limiting the amount of apples that can be added to the diet.

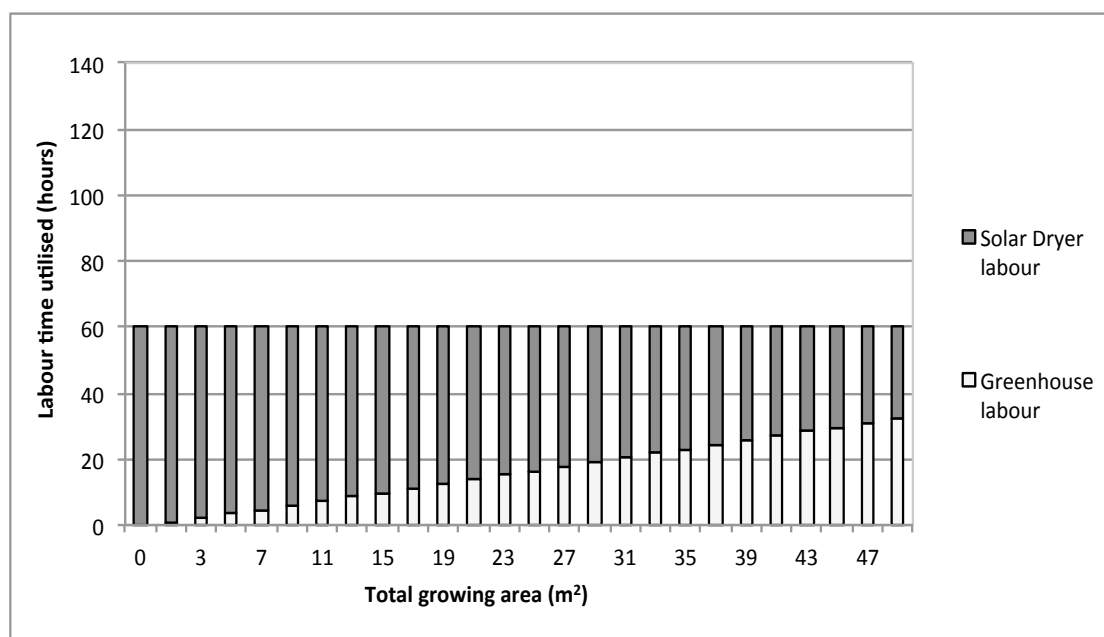


Figure 32 - Total labour time plotted against increasing total greenhouse growing area.

The distribution of labour time (Figure 32) shows that the maximum amount is allocated to tending the greenhouse crops at all times (only being restricted by the total available growing area). As the total greenhouse growing area increases, more labour time is allocated, at the expense of labour time allocated for drying which decreases the portion of apples included in the diet. This indicates that for each hour of labour time, more overall nutritional benefit is derived from the greenhouse crops than from the dryer crops.

This suggests that it is either necessary to decrease the labour time involved for drying apples, or to dry the apples at a later time not within the harvest season when more labour time is available. These two scenarios have been explored further using the linear programming model.

Table 20 shows the difference in nutrient levels (compared to the greenhouse alone scenario) and total harvest amounts of apples. Figure 33 shows the allocation of labour time. Doubling the allowable labour time per season doubles the amount of apples that can be dried but only results in a minimal increase in the NAR for each nutrient. Again, the maximum amount of labour time is allocated to the greenhouse production at the expense of solar dryer production.

Table 20 – Increase in percentage points of NAR with the addition of apples for different growing areas with labour time constraint increased to 120 hours.

Total Greenhouse Growing Area (m ²)	Total Apples (kg)	Increase in NAR (pp)					
		Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy
0	29	0.4	1.1	0.1	1.5	0.8	1.7
5	28	0.3	1.1	0.1	1.5	0.8	1.7
10	27	0.3	1.0	0.1	1.5	0.7	1.6
15	27	0.3	1.0	0.1	1.4	0.7	1.6
20	26	0.3	1.0	0.1	1.4	0.7	1.5
25	25	0.3	0.9	0.1	1.3	0.6	1.5
30	25	0.3	0.9	0.1	1.3	0.6	1.4
35	24	0.3	0.9	0.1	1.3	0.6	1.4
40	23	0.3	0.8	0.1	1.2	0.5	1.3
45	22	0.3	0.8	0.1	1.2	0.5	1.3
50	21	0.3	0.8	0.1	1.1	0.5	1.3

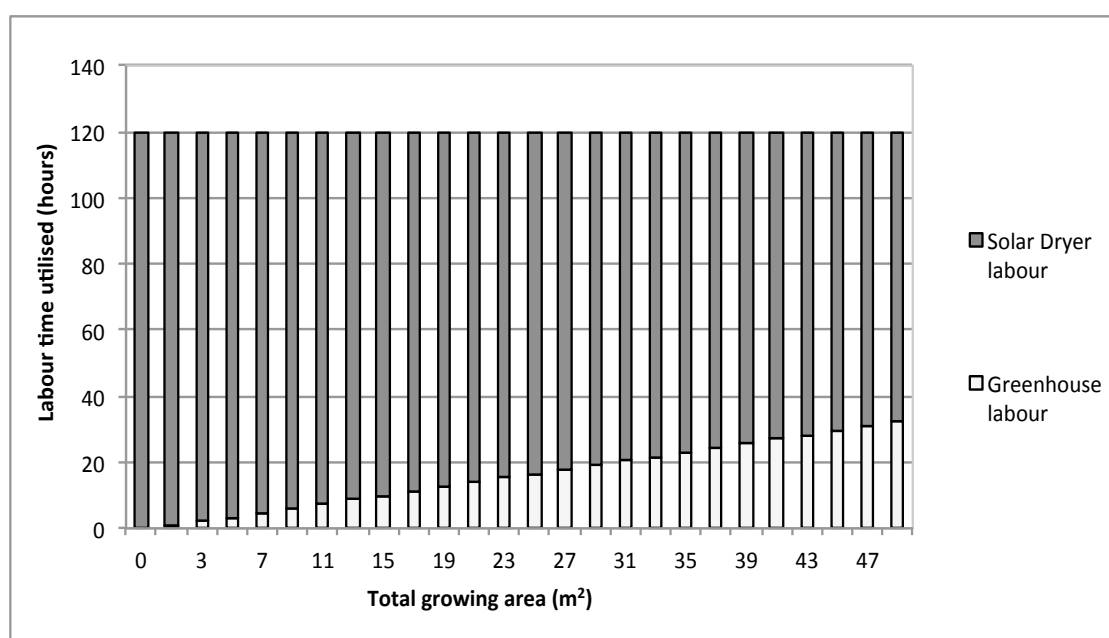
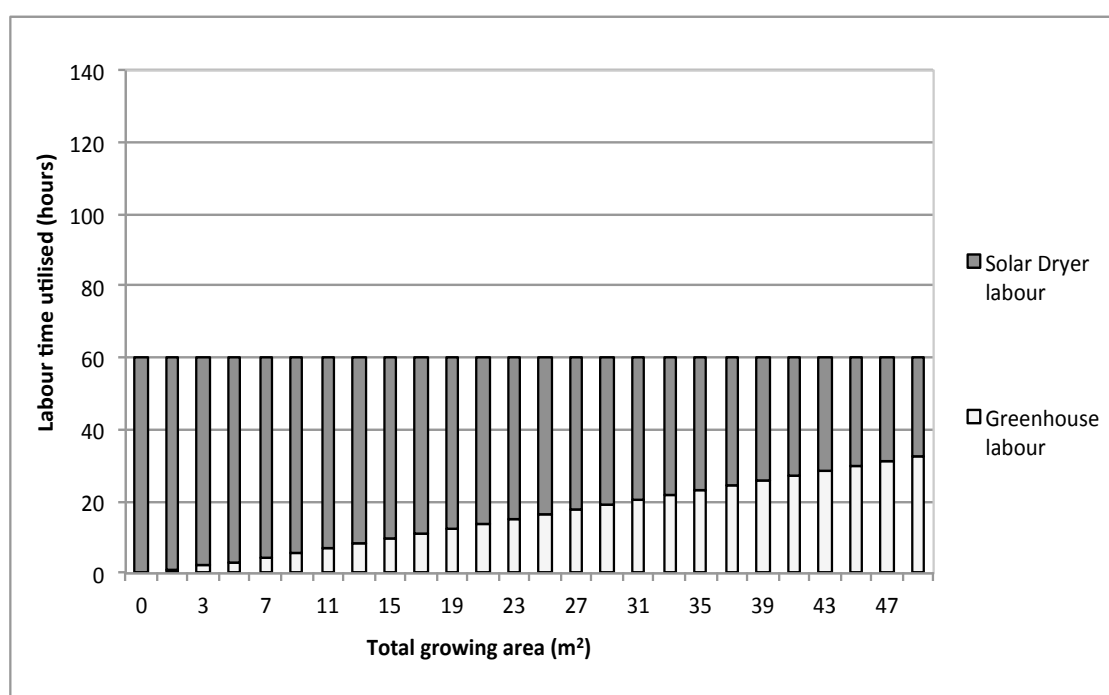
**Figure 33 - Total labour time plotted against increasing total greenhouse growing area with labour time constraint increased to 120 hours.**

Table 21 and Figure 34 show the difference in nutrient levels and labour time results when the labour coefficient for the solar dryer in the labour constraint equation (Eq. 11) is reduced from 4.1 to 0.66 hours per kg, similar to that of the greenhouse production per square metre. It is not possible to use an identical labour time parameter for the greenhouse and solar dryer since the labour time for the greenhouse is based on hours per square metre, and the amount of produce varies according to the crop distribution.

Table 21 – Increase in percentage points of NAR with the addition of apples for different growing areas with dryer labour coefficient decreased to 0.66.

Total Greenhouse Growing Area (m ²)	Total Apples (kg)	Increase in NAR (pp)					
		Protein	Iron	Vitamin A	Vitamin C	Zinc	Energy
0	91	1.1	3.4	0.4	4.8	1.4	5.3
5	86	1.0	3.2	0.3	4.6	1.3	5.1
10	80	1.0	3.0	0.3	4.3	1.2	4.7
15	76	0.9	2.8	0.3	4.1	1.2	4.5
20	70	0.9	2.6	0.3	3.8	1.1	4.2
25	66	0.8	2.5	0.3	3.5	1.0	3.9
30	62	0.7	2.2	0.2	3.2	0.9	3.6
35	56	0.7	2.1	0.2	3.0	0.9	3.3
40	52	0.6	1.9	0.2	2.7	0.8	3.0
45	46	0.6	1.7	0.2	2.5	0.7	2.8
50	42	0.5	1.6	0.2	2.3	0.6	2.5

**Figure 34 - Total labour time and drying time plotted against increasing total greenhouse growing area with solar dryer labour coefficient reduced to 0.66.**

In both the above scenarios, nutrient levels are improved but not by a significant amount. This is possibly due to the lower overall nutrient content of apples. The fact that the maximum possible labour time is allocated to greenhouse production shows that the same or better nutritional improvements can be achieved with less labour with the greenhouse alone. This is important in the Humla context,

and in fact in any developing country context, because reducing labour allows time for education and income generation activities. The addition of apples to the diet however does improve diversity in available food and was observed to be a popular addition to the diet during fieldwork.

In both of the above examples, calculation of the NARs for each nutrient was found to be a useful tool to compare results from different scenarios. The MAR value, however, did not reflect significant changes in the NARs and therefore wasn't useful in reflecting improvements in the results. This is possible due to the fact that only six nutrients were selected for analysis, which are much less than in examples in previous research.

5.4 Summary and Conclusion

In this chapter, the current nutritional adequacy of a typical poor Humla family was quantified, from which the nutritional criteria used to assess the impact of the two technologies could be established. The potential impact of each technology on nutrition was explored using a linear programming model, subject to local and cultural constraints. These results were used to determine which crops would be most suitable and estimate the quantities required prior to experimentation, and establish which nutritional deficiencies could be realistically addressed.

The quantitative analysis of current nutritional status in Section 5.1.1 showed the local diet over the winter period is seriously lacking in vitamins and minerals, particularly vitamin A and vitamin C for both of which 0% of the RNI were being met. A lack of bulk food is also indicated by the low protein (76.7% RNI) and energy levels (60% RNI). Zinc levels were also low at only 51.7% RNI. This supports information found in literature presented in Chapter 2 and indicates that food consumption needs to be increased and diversified.

The simulated inclusion of greenhouse produce in the diet addressed vitamin A (up to 446% RNI), vitamin C (up to 224% RNI) and iron deficiencies (up to 103% RNI) and mostly addressed protein deficiencies (up to 94% RNI). But no significant increases in energy (67% RNI) or zinc levels (61% RNI) were apparent. The main constraints on the amount of vegetables that could be produced were portion size and total available growing area in the greenhouse. RNI levels are

met for all of iron, vitamin A and C, and mostly met for protein when the greenhouse area is 25 m², with a combination of carrot and swiss chard, however diversity in ingredients doesn't improve until the growing area is 30 m² or more and cauliflower features in the results. This suggests that a total growing area of between 25 – 35m² would be sufficient to address most nutrition deficiencies and palatability.

One clear result is that potatoes, included for their high energy content, do not contribute enough to improving nutrition to have been allocated any growing area in the greenhouse. This indicates that nutritional contribution of potatoes per square metre is not high enough to contribute to improving energy levels compared to the density of other nutrients in other crops. The fact that other locally available high energy crops have low yield per square meter and low levels of other nutrients suggests that energy cannot be addressed with the greenhouse crops if overall nutrition improvement is the main aim and if crop choices are restricted to those locally available.

The initial simulation including apples showed little or no improvement in the previous scenario with greenhouse produce only. The amount of apples that could be dried was limited by available labour time, and the preferential allocation of labour time to greenhouse production over solar dryer production indicated that the same or better nutritional outcome could be achieved with the greenhouse produce with less labour time. Similar outcomes occurred even when the labour time constraint was increased and when the labour coefficient for the solar dryer was reduced. The use of nutrient adequacy ratios (NARs) was found to be useful to compare outcomes of different scenarios, unlike the mean adequacy ratios (MARs) which did not show clear differences.

These results provide a starting point for the experimental investigation of the two technologies in Chapters 6 and 7. They indicate that, in theory, a greenhouse of between 25 – 30 m² would be suitable to improve the nutritional status and palatability of a typical Humla family diet, and that carrots, spinach, swiss chard and cauliflower would be suitable crops. Although the above results indicate that drying apples do not contribute significantly to nutrition, this is based on assumptions and information in literature that need to be verified with experimental results. Apples also contribute to the diversity of the diet, which is not captured in the linear programming model.

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Chapter 6

Greenhouse Design Selection, Construction and Experimentation

6 Greenhouse Design Selection, Construction and Experimentation

As stated in Chapter 2, there is a significant imbalance in food availability throughout the year in Humla. The purpose of the greenhouse is to allow fresh vegetables to be grown during winter when outside conditions would otherwise make this impossible. These vegetables would then be combined with those dried and stored from the solar dryer to improve overall nutrition.

The purpose of this chapter is to outline the selection and construction of an appropriate greenhouse design for the purposes of this research and to assess its performance through experimentation. The aims of the experimentation process are to determine that the chosen design can be built and operated, to establish a baseline from which improvements can be made via modelling and simulation, and to generate data that will be used to validate the simulation models. In Section 6.1, some basic greenhouse theory is presented along with specific criteria for design selection in Humla, taking into account local constraints such as cost, material and resource availability. In Section 6.2, existing high altitude greenhouse designs are considered and compared according to these criteria. Section 6.3 outlines the construction process, including design modifications that had to be made to suit the local context and how this is reflected in the cost. In Section 6.4, the experimentation method is outlined, followed by presentation of the results in Section 6.5.

6.1 Greenhouse theory and design selection criteria

A greenhouse is defined as a space enclosed or partially enclosed with transparent material for propagation, growth and / or storage of living plants (Garzoli 1988), primarily at times when they would not survive outside. The structure is essentially a "heat trap" (Garzoli 1988). Solar radiation passes through the transparent covering, heating surfaces inside which then heat the indoor air via convection when it passes over them. The warm air is then not able to move away because it is trapped in the enclosed space. If the amount of solar heat gain exceeds losses due to conduction or air leakage, the air temperature in the greenhouse will become warmer than the surrounding air.

A greenhouse microclimate differs from the external climate due to increased temperatures, increased humidity, reduced solar radiation and increased carbon dioxide levels. All of these factors influence plant growth, but temperature is considered to be the most dominant climatic factor, since the rate of growth of many plants can be regulated according to air temperature alone (Garzoli 1988). Temperature control is achieved through the careful management of heat gain, loss and storage in the greenhouse. In the following section, factors that effect temperature regulation will be discussed. This will focus primarily on unheated or solar greenhouses, which are designed to passively regulate their own temperatures and are most suitable for remote areas in developing countries. The main components that affect temperature are the glazing, thermal mass and ventilation.

6.1.1 Glazing

Greenhouse coverings or glazing play an important part in maintaining the greenhouse microclimate since they influence light transmittance, heat gain and heat loss. Light transmittance and heat gain through the cover are determined by the optical properties of the glazing material and slope of the surface. Regardless of the greenhouse cover, some light is transmitted, some is reflected and some is absorbed (Garzoli 1988). The highest transmissivity for the majority of glazing materials occurs when the direction of the solar radiation is perpendicular to the surface (MacKinnon 1978). Since the sun direction varies significantly, the slope of the glazed surface must be designed to achieve the best overall solar access for the greenhouse operational period.

Heat loss through the cover is a two-part process. It takes place at the inner and outer cover surfaces as well as through the material itself. The inside surface absorbs heat from the greenhouse air by convective heat transfer from the warmer air, by intercepting thermal radiation emitted by the plants, floor and other surfaces or via condensation. This heat is then conducted to the cooler outside surface where it is lost to the environment by convection to the outside air and by thermal radiation to the sky and surroundings. Due to the large area of glazing on a greenhouse, heat loss or gain through the glazing can be significant.

6.1.2 Thermal mass for heat storage

In traditional greenhouses commonly used in developed countries, auxiliary heating is employed to maintain adequate growing temperatures. In areas where

this is not possible, thermal mass is used to passively regulate temperatures. Excessive heat during the day is absorbed, stored and then released at night when air temperatures drop. Typically, thermal mass can take the form of water storage containers or masonry walls.

6.1.3 Ventilation

Ventilation plays an important role in regulating environmental conditions inside the greenhouse. Almost all greenhouses require ventilation during periods of high solar radiation in order to limit internal air temperature. In addition to this, it is the main method used to remove water vapour produced by plants during transpiration and respiration and regulate humidity (Bailey 2000). Although humidity regulation is not as critical as temperature regulation, it is still necessary to keep humidity below certain levels to prevent the propagation of fungal diseases on plants (Buffington et al. 2010). To be effective, ventilation must provide sufficient air exchange between the greenhouse and surroundings, as well as good mixing between incoming air and greenhouse air. It must also create internal air movement that induces good heat and mass transfer between plants and air (Bailey 2000).

In remote areas without electricity, passive or natural greenhouse ventilation is used to provide adequate air movement. Natural ventilation takes place as the result of the interaction of pressure differences created across an open ventilator and the flow characteristics of the vent (Bailey 2000). It works well in cool and mild weather conditions when there is a significant difference between indoor and outdoor temperatures (Garzoli 1988). Natural ventilation is improved by having low inlet vents at the front or side of a greenhouse and high outlet vents in the uppermost section of the roof; as a result, taller greenhouses are more likely to have better ventilation characteristics. Wind, particularly a cross wind, also increases the ventilation rate (Garzoli 1988).

6.1.4 Design selection and performance criteria

Based on the discussion of greenhouse theory in the above sections and consideration of the context in which the greenhouse must operate, this section will define some necessary criteria to determine the suitability of potential designs, govern design modifications and assess the performance of the chosen design.

Due to the remote context, the design selection and modification process will be governed by the “appropriateness” criteria outlined in Chapter 4. These stipulate that greenhouses must be built largely with local materials and expertise and be able to withstand extreme conditions common in mountain areas. It is acknowledged that not all materials will be able to be sourced locally, but those that cannot must be easily transportable via aeroplane or overland. The greenhouse must also be able to be constructed and managed by local people, on a household basis, within available time limits.

For the greenhouse to be appropriate, it must also be affordable for local people. Affordability criteria is based on the amounts local people have been willing to pay for other appropriate technologies, and also results from surveys in nearby districts. As shown by the widespread implementation of improved cooking stoves by RIDS Nepal in Humla, most families can afford to pay around \$US 50 for minor technologies (RIDS Nepal 2012). A greenhouse, however, would possibly warrant a larger investment since it is a major technology. In nearby Jumla, a survey by World Vision showed that farmers would be willing to pay up to \$US 500 for a solar greenhouse (pers. comm P Freere, 13 December 2012). Since Jumla has a slightly higher estimated per capita income than Humla, \$US 203 compared to \$US 186 (UNDP 2004, p. 156), it is estimated that the maximum cost for the greenhouse for Humla should be around \$US 450 or around 40,500 NPR.

Unlike traditional greenhouses used in developed countries, greenhouses in Humla must be able to regulate their own temperature and not rely on auxiliary heating or cooling. Since the aim of this research is to improve rather than optimise crop production, it is considered sufficient to aim to keep the greenhouse conditions within acceptable ranges rather than at optimal values. The main focus will be on temperature, based on the fact that this is the dominant factor for plant growth, with some consideration of humidity also. According to Garzoli (1988), an air temperature range of between 10 – 32°C is suitable for growing most plants. In addition to this, Maynard and Hochmuth (1997) recommend a soil temperature range of between 7 - 24°C to allow germination. Although less important than temperature, a general range of between 50 – 70 % for relative humidity is considered optimal for plant growth (Vaisala 2011), with a maximum of 90% to reduce risk of disease (Buffington et al. 2010). Since the focus of this research is not on optimisation, the performance criterion for relative humidity will involve keeping it below 90%.

6.2 Design Selection

Due to the specific nature of remote, mountain context in which the greenhouse must operate, potential designs were selected from those already in operation in other mountain areas. The following section outlines two different high altitude solar greenhouse designs and compares them to determine which would be the most suitable for the Humla region.

6.2.1 GERES/LEHO polyethylene – walled design

The basic GERES design consists of a structure with solid masonry walls on the north, east and west sides, a glazed south sloping face and a sloping roof facing north (Figure 35). The glazing is single layer UV stabilized polyethylene and angled in such a way to transmit the maximum amount of solar radiation to the interior. This design has been adapted to be applicable in high altitudes, to withstand high snowfall and very low temperatures and to be affordable for local farmers.



Figure 35 – Solar greenhouses in Ladakh (Photos – S Candy).

The angle of the lower section is 50° or more from the horizontal to transmit solar radiation in the winter season when the sun is low in the sky. The angle of the upper section is 25° or more to transmit midday solar radiation and allow small amounts of snow to slide off. Figure 36 shows the cross section and footprint of the GERES design.

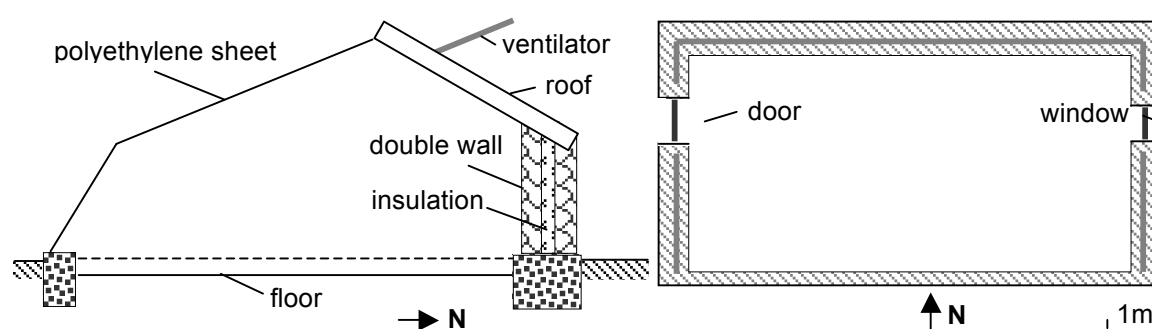


Figure 36 – Cross section elevation and plan view of GERES greenhouse.

The walls are composed of three layers: an outer load bearing wall built with mud brick, rammed earth or stone; a thinner inner wall used to store heat during the day and release it at night, also built from mud brick, rammed earth or stone; and an insulating layer of materials like straw, sawdust or dry grass in between. The roof on the north side is constructed from layers of wooden sticks, straw and soil. This solid construction is intended to limit heat loss and is tilted at an angle of 35° to avoid shading in winter and reduce the interior volume.

Ventilation is provided with a door and a window on opposite walls and two roof ventilators that are manually operated. Both the door, window and ventilator shutters are constructed using a thick wooden frame and thin outer sheets of plywood, with dry grass again being used as insulation in the middle. The combination of ventilation and thermal heat storage in the masonry walls regulates the temperature and humidity within the greenhouse. An optional night curtain on the inside of the glazing can also be used to further reduce night-time heat losses. This basic design is used extensively in the mountain regions of Ladakh in India, Mustang in Nepal and in parts of China. The cost of these greenhouses, based on the Ladakh context, is 25,000 Rs (Indian rupees) (pers. comm. T Tokmet, 15 May 2008) or approximately \$US 450 (based on conversion rate of 55 Rs to one US dollar).

6.2.2 SNV insulated tunnel design

Although the walled greenhouse design is known as the typical high altitude greenhouse design, more recently an alternative design has been proposed. Following an exploratory visit to Mustang in Nepal, Nienhuys (2003) stated that although the heavy stone construction of the GERES greenhouse design successfully moderated air temperature inside the greenhouse, it did little to

increase soil temperature. This prevented the early transplanting of seedlings into greenhouse plant beds. In addition to this, the stone wall construction was costly and labour intensive for farmers.

As an alternative to the GERES solar greenhouse design, Nienhuys proposed a tunnel shaped structure with an insulated layer of topsoil (Figure 37). The intention was that the insulated soil would be warmed during the day by solar radiation and the stored heat would be released slowly during the night, maintaining both an adequate soil and air temperature in the greenhouse.

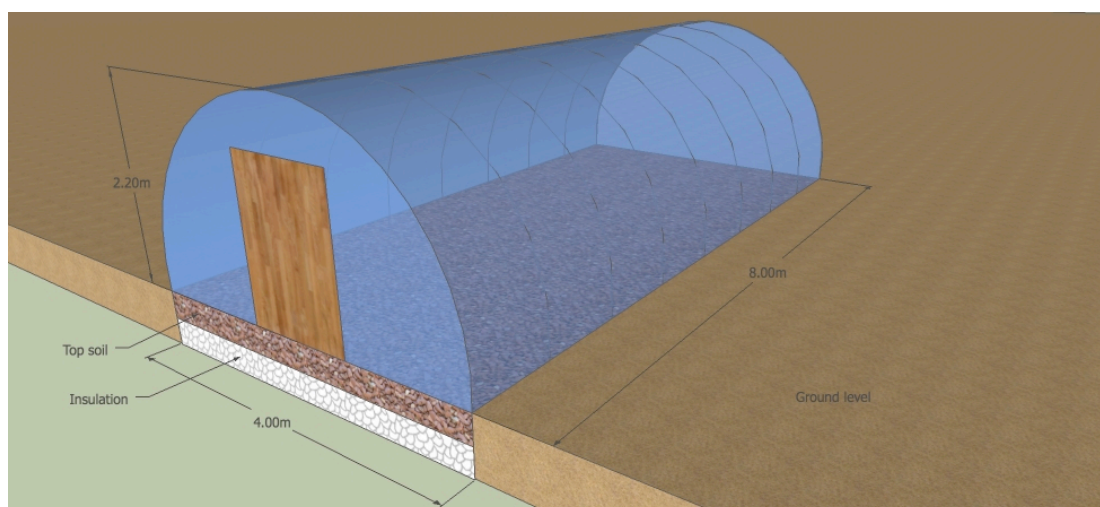


Figure 37 – Tunnel greenhouse design with insulated soil.

The tunnel is constructed from a bow-rib and girder framework of bamboo sticks covered by polyethylene sheets and has a height of 2.2 m, width of 4 m and length of 8 m. Allowing for paths between growing beds, this would provide roughly the same amount of growing area as the GERES design. The underground insulation is made from plastic fibre bags filled with waste plastic such as water bottles, shopping bags and food packaging, with the sealed water bottles providing structure so that the plastic waste does not get compacted by the soil above. It is then covered with topsoil to a depth of approximately 30 cm. Gutters are dug along each side of the soil to provide drainage and collect nutrient rich excess water (preventing it from seeping underground).

It is suggested that a flatly filled plastic fibre bag has an insulation value similar to that of 8cm glass wool batts (Nienhuys 2003) and is significantly less expensive. An added advantage of using plastic waste for insulation is that it

removes the waste from mountain areas where it is currently polluting the natural environment. It is not stated by Nienhuys how much this design would cost, but it is expected to be around US \$100 - \$200 based on the costs of the plastic and the wood frame.

6.2.3 Comparison of greenhouse designs

The GERES and SNV solar greenhouse designs differ significantly in terms of both construction and operation and it would be difficult to do a quantitative comparison of the two designs without performing a full thermal evaluation. However, findings from greenhouse research in mountain areas in India, a recent evaluation of a Humla greenhouse and fieldwork observations can be used to determine the suitability of each design in the Humla context. The main features of each of the three designs are summarised in Table 22.

Table 22 – Comparison of main features of greenhouse designs

Main Features	SNV Design	HARS Greenhouse	Ladakh Greenhouse
Style	Tunnel	Walled	Walled
Cost	Low	Moderate	High
Potential yield	Moderate	Moderate	High
Walls	Plastic	Single masonry	Double masonry
Ventilation	None	Minimal	Good
Temperature Variation	High	Moderate	Low
Durability	Low	Moderate	High
Availability of materials locally	Low	High	High

Singh (2000) investigated different solar greenhouse structures for winter vegetable production in Ladakh and compared performance and cost. Both a tunnel greenhouse (without soil insulation) and a walled design were tested and it was found that there was a much more rapid diurnal heat gain and loss in the tunnel design compared to the walled design. This can be attributed to the smaller amount of thermal mass in the tunnel design. Cost data was based on an operational life of three and two years for the walled design and tunnel design respectively. Although the cost of the walled design was 50% more per square metre per year than that of the tunnel design, the average yield of vegetables per square metre per year over the winter season was more than double due to better temperature regulation. This resulted in a cost of production per kilogram of produce of 10.57 Rs for the walled design compared to 13.21 Rs for the tunnel.

As mentioned in Chapter 3, Fuller et al. (2009) investigated the HARS experimental solar greenhouse in Simikot that was similar in design to the Ladakh greenhouse but with only single masonry walls and a shallower angle for the glazing. Fuller's initial evaluation found that the HARS greenhouse air temperature range on a typical January day was between 2°C overnight and 26°C in the middle of the day and soil temperatures at 200mm below the surface do not fall below 9°C. The temperature ranges in the existing Humla greenhouse show that the soil is sufficiently warm to allow germination (between 7 – 24°C), but that air temperatures overnight are lower than the recommended range (10 - 32°C). This indicates that soil insulation is not needed in Humla conditions, but that increased thermal mass is required to moderate air temperature.

The Nienhuys design does not incorporate ventilation into the design, which would have implications for both air temperature and humidity. Although no data is available for humidity levels, tests performed on uninsulated tunnel greenhouses in nearby Jumla by World Vision showed that daytime air temperatures reached up to 50°C (pers. comm P Freere, 13 December 2012). This indicates that if the SNV design were to be built in Humla, the design would need to be modified to incorporate ventilation, which could increase costs. The GERES design already incorporates ventilation through the door, window and roof vents.

Other considerations such as durability and available materials were also taken into account. The Nienhuys design would be significantly cheaper to construct than the GERES design, but it would be more susceptible to damage from strong winds and adverse weather. It would also be difficult to find a suitable material for the insulation, since Humla does not have the same volume of trekking traffic as Mustang and therefore has much less plastic waste. It is possible that straw could be used as insulation, however it is thought that this would compress under the weight of the soil above, reducing its thermal resistance. It is questionable whether the performance of the uninsulated tunnel design would be comparable to the walled design, but without insulation it is even more unlikely. In the tests performed by World Vision in nearby Jumla mentioned earlier, it was found that, in addition to excessive daytime temperatures, overnight temperatures in uninsulated tunnel greenhouses matched ambient temperatures overnight (pers. comm P Freere, 13 December 2012). These results indicate that substantial changes would need to be made to the tunnel greenhouse design to ensure better

temperature regulation, which could increase costs significantly. Therefore, based on thermal performance and durability, the GERES design is considered the most suitable for Humla. The construction process and design modifications for the experimental greenhouse are outlined in the following section.

6.3 Construction

According to the published GERES construction manual (Stauffer et al. 2004), the 1A design would be most suitable for the Humla climate based on temperature data collected by Fuller et al. (2009). This is a stand-alone design, intended to be built on a flat surface in a cold climate with minimum winter temperatures above -10°C . Although integrating one wall of the greenhouse with the farmhouse would reduce materials, cost and heat losses, this would not be feasible in Humla due to the close proximity of houses in villages (Figure 38).



Figure 38 – Proximity of houses in Kholi village, Humla (Photo – S Candy).

To adapt this design for Humla, a number of changes were necessary related to materials, size, ventilation and glazing. This section outlines the construction process of the greenhouse including walls and openings, roof construction and sizing, and ventilation and glazing.

6.3.1 Walls and openings

The experimental greenhouse was constructed for the purposes of this research during September 2008 in front of the RIDS Nepal field office in Darapori village, five hours walk from Simikot. The site is in a horizontal terraced field on the south-facing side of the valley, overlooking the Karnali river at an altitude of 2365 m (Figure 39). The construction process was managed by the author, with local skilled tradesmen employed for all carpentry and masonry, and additional unskilled tasks being performed by the author and RIDS Nepal staff. Materials such as stone, wood and straw were sourced locally, while additional materials were flown in from Nepalgunj. UV stabilised plastic sheets were sourced in India, transported to Kathmandu and then to Humla.



Figure 39 – Greenhouse site in Darapori village; excavating foundations.

Wall construction began with digging and laying of stone foundations to a depth of 1.5 feet (45 cm) (Figure 39 – right). Local construction practices had implications for the choice of wall materials. Instead of mud brick that is used in the GERES greenhouse, dry stone wall construction was used as this is the traditional method used in Humla (Figure 40 - left). As a result, it was not possible to adhere to the recommended inner wall thickness of 15 cm. For stability, the inner wall had to be at least 30 cm in thickness, the same as the outer wall (Figure 40 - right).



Figure 40 – Stone wall construction; inner and outer wall.

The cavity between the wall layers was filled with straw to serve as insulation. With dry stone construction, it was not possible to have insulation throughout the entire wall area, since the sections with sloped edges may also become unstable unless solid. Figure 41 shows a scale drawing of the greenhouse walls, modified in the diagram to be semi-transparent to show the distribution of straw insulation between the inner and outer wall layers. Figure 42 (left) shows the straw insulation being installed in the back wall.

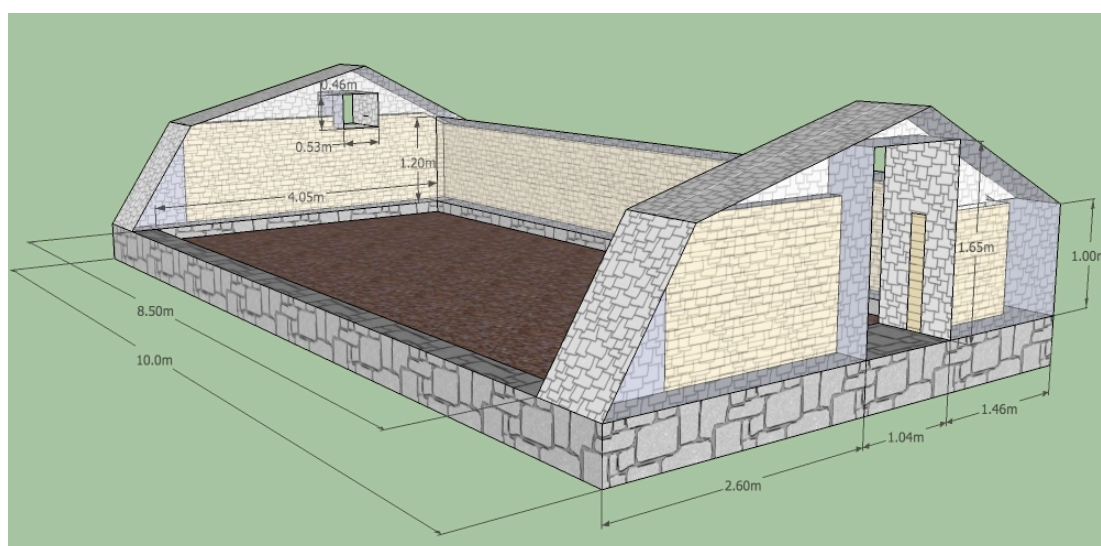


Figure 41 – Scale drawing of greenhouse walls showing inner insulation.

In line with common local building methods, the greenhouse walls were covered in a layer of mud when complete to seal them (Figure 42 – centre and right).



Figure 42 – Filling insulation in back wall; sealing walls with mud.

The door frame and window frame and shutter were constructed from local pine (Figure 43). The door itself was constructed using a wooden frame with wood planks on one side, sheet metal on the other and an inner cavity filled with straw insulation. Sheet metal had to be used instead of the recommended plywood, since the latter could not be sourced in Humla or Nepalgunj. The roof ventilators were constructed in the same way as the door. The window shutter was considered to be too small to require insulation, since heat loss would be minimal, so it was made from wooden planks only. An additional screen door was also added to prevent animals entering the greenhouse so that the main door could be left open for ventilation if necessary.



Figure 43 – Door frame; door panel construction; screen door.

6.3.2 Roof construction and sizing.

The solid section of the roof was constructed from layers of wood, straw, plastic and soil (Figure 44). Although the GERES construction manual recommends sticks for the wood layer it was constructed from rough wooden planks instead. Sticks

are in short supply because they are already being gathered by local villagers as firewood. The plastic layer was not part of the original GERES design, however local tradesmen recommended it be added for water-proofing. This is the normal construction method in Humla due to the fact that the climate is slightly warmer and less arid than Ladakh and Mustang, for which the GERES design was developed.



Figure 44 – Wooden planks on roof; adding straw layer; soil over plastic layer.

Changes had to be made to the size of the cross section of the greenhouse due to constraints with construction materials. The standard wooden planks available from local wood cutters are shorter than that required for the roof in the GERES design, so the roof had to be shortened by 15 cm. Due to difficulties in acquiring sufficient stone, the north wall was also lowered. This lowered the highest point of the roof, reduced the angle of the upper section of the glazing and reduced the volume of the greenhouse. In addition to this, the sheets of UV resistant polyethylene available were narrower than that specified in the GERES construction manual, so the length of the greenhouse along the north-south axis also had to be reduced. Due to the thicker inner walls, the inside growing area was also reduced. Figure 45 shows a scale drawing of the modified cross section and footprint of the Humla greenhouse.

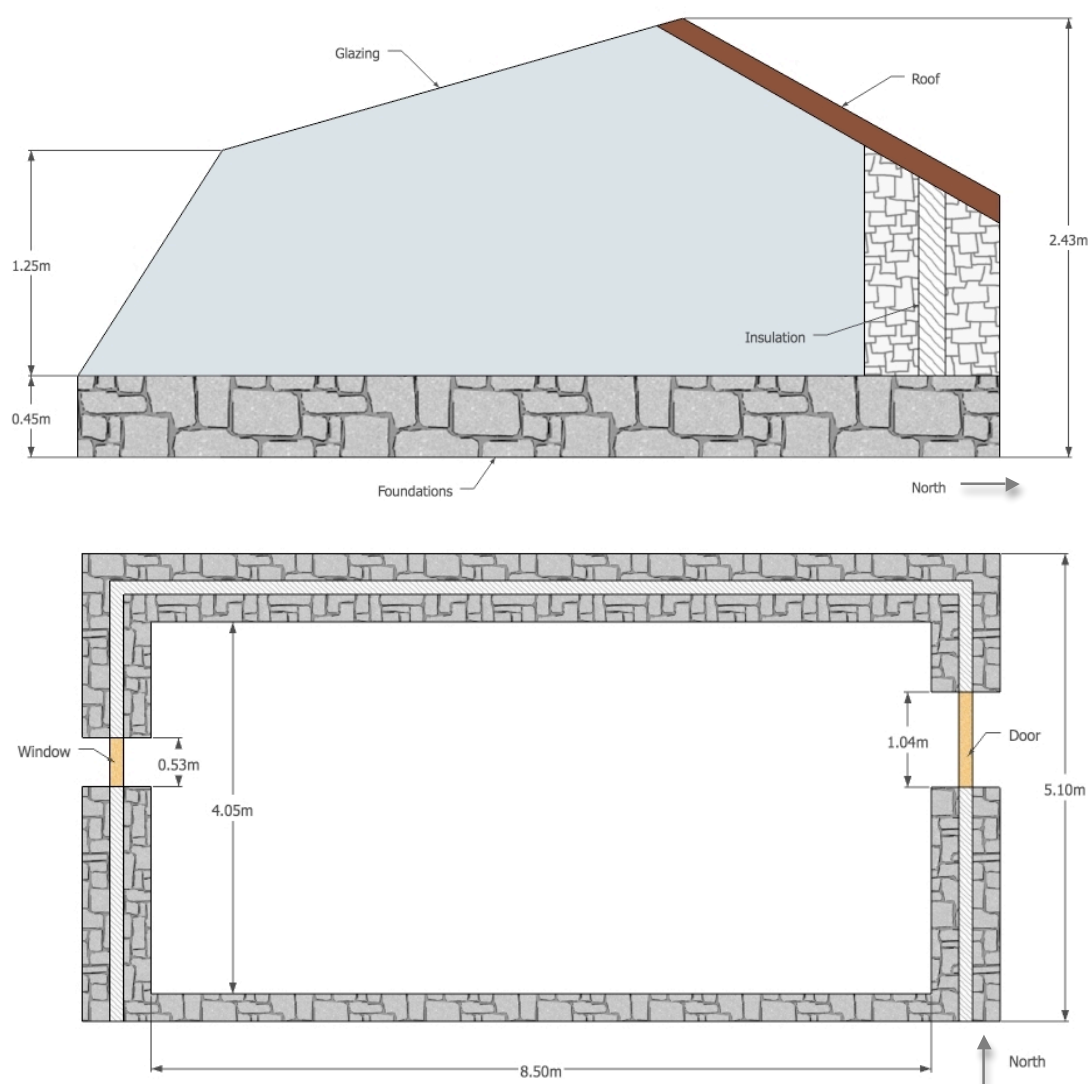


Figure 45 – Cross section elevation and plan view of Humla greenhouse.

6.3.3 Ventilation and Glazing

Based on the thermal evaluation of the existing Humla greenhouse by Fuller et al. (2009), double glazing has been added to the greenhouse to reduce heat loss during the night. It has been attached to the underside of the wooden frame inside the greenhouse and sealed with thin strips of wood nailed down along the beams (Figure 46- left). The outer edges of both the external and internal layers of plastic sheeting have been sealed using heavy wooden planks placed along the top and edges of the side walls (Figure 46- right). To counteract any subsequent

temperature rises during the day, extra ventilation flaps have been added in the front corners of the greenhouse (Figure 46- right).



Figure 46 - Inside Humla greenhouse; outside Humla greenhouse.

The greenhouse is surrounded by mountains and is only exposed to direct sunlight between 9.30am and 3.30pm over the winter period. To maintain the temperature in the greenhouse, the vents are manually opened at 10am in the morning and closed at 3pm each afternoon. On cloudy and cold days, the vents remain closed all day.

6.3.4 Crop distribution

The growing area inside the greenhouse was divided into five separate beds as shown in Figure 47. The horizontal path follows the line of the highest point of the roof (see Figure 45) to enable easy access. The area of each bed and the total growing area is shown in Table 22.

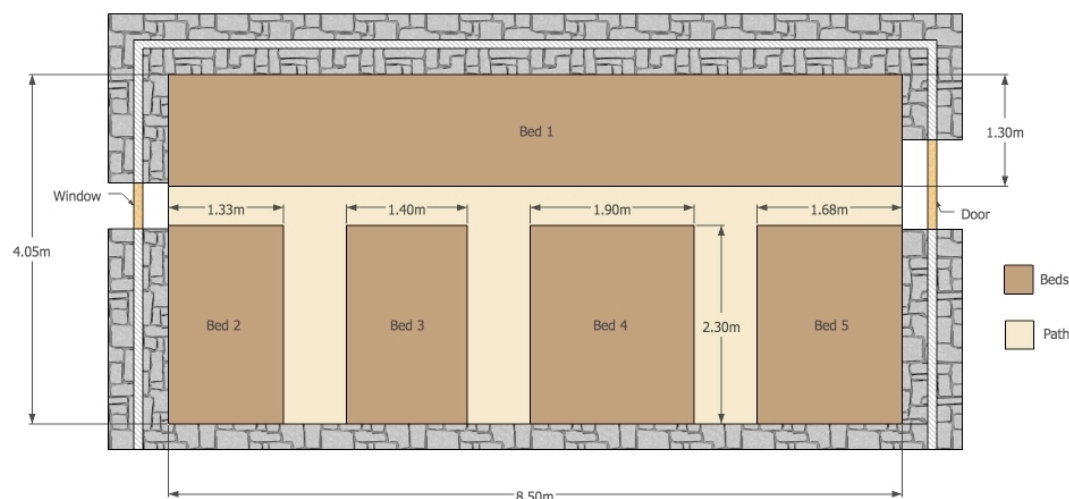


Figure 47 – Growing area distribution in greenhouse.

Table 23 – Area of each growing bed and total growing area.

Bed	Area (m ²)
1	11.05
2	3.06
3	3.22
4	4.37
5	3.86
Total	25.6

At the beginning of November in 2008 and 2009, cauliflower, spinach, swiss chard and carrots were planted in the greenhouse. They were distributed according to Table 24. The aim was to validate the assumptions related to yield per square metre per month made in the linear programming model.

Table 24 – Crop distribution.

Crop	Bed	Growing area (m ²)
Cauliflower	2	3.06
Spinach	1 & 4	15.42
Swiss Chard	5	4.08
Carrot	3	1.61*

*Note that half of bed 3 was planted with onion by local NGO staff for their specific needs, which was not included in the analysis.

6.3.5 Cost

The greenhouse required one month for construction and, where possible, materials were sourced locally. Materials that were not available locally, such as hinges, paint, wire and galvanised iron sheets were sourced in Nepalgunj and transported by air to Humla. The UV stabilized plastic sheets had been purchased from India and transported to Nepal. The summary of construction costs is shown below in Table 25.

Table 25 – Breakdown of construction costs for greenhouse (90 NPR ≈ 1 USD).

<i>Item</i>	<i>Amount</i>	<i>Unit cost (NPR)</i>	<i>Total cost (NPR)</i>
Excavation	-	-	6000
Stone	4 charta*	6000 per charta*	24000
Wood (rough)	51 planks	50 per plank	2550
Wood (cut)	26.6 ft ³	150 per ft ³	3990
Wood (beams)	6 beams	150 per beam	900
Plastic sheet	110 m ²	23 per m ²	2530
External materials	-	-	10759
Transportation costs	107 kg	80 per kg	8560
Carpentry / Masonry	28 days, 2 workers	500 per worker per day	28000
Total			87289

*One charta is a stone volume measurement equivalent to 5 ft x 3 ft x 3ft or 1.3 m³.

The total cost of construction was approximately \$US 1000 (assuming 90 NPR per US dollar). This is more than double the maximum cost stipulated in the affordability criteria in Section 6.1.4 and is therefore significantly more than a local family could afford. Although costs may have been inflated due to foreign involvement in the project, it is clear that the overall costs are high and the two largest contributors are skilled labour and stone. Stone was recommended as an alternative to mud brick in the GERES construction manual, however the higher cost of this building material was not considered. In Humla, it is necessary to chip stone manually from nearby cliffs for construction, which significantly increases the costs and has implications for the appropriateness of the design in the Humla context. An improved design that used less stone would lower both material costs and labour costs, since wall construction comprised approximately 70% of skilled labour time.

It was decided to use skilled labour for the construction of the greenhouse to ensure that the best possible prototype was built so that the best results could be achieved. An alternative to this is to have farmers source their own stone locally, and build the greenhouse themselves. Wood and external materials would still need to be purchased. Due to deforestation in the area, wood is a valuable commodity and regulations exist to prevent its over-use, preventing farmers from sourcing it themselves. A cost breakdown for this scenario is shown below in Table 26, based on a value of 150 NPR per day for unskilled labour (pers. comm, P.Freere, 26 July 2012). It has also been assumed that the stone gathering and construction process will take twice as long if unskilled labour is used.

Table 26 – Breakdown of construction costs for greenhouse assuming unskilled labour is used (90 NPR $\approx$ 1 USD).

<i>Item</i>	<i>Amount</i>	<i>Unit cost (NPR)</i>	<i>Total cost (NPR)</i>
Excavation	3 days, 3 workers	150 per worker per day	1350
Stone Gathering	30 days, 2 workers	150 per worker per day	9000
Wood (rough)	51 planks	50 per plank	2550
Wood (cut)	26.6 ft ³	150 per ft ³	3990
Wood (beams)	6 beams	150 per beam	900
Plastic sheet	110 m ²	23 per m ²	2530
External materials	-	-	10759
Transportation costs	107 kg	80 per kg	8560
Carpentry and Masonry	60 days, 2 workers	150 per worker per day	18000
Total			57639

By using unskilled labour, the cost of the greenhouse construction is reduced by 30% to \$US 700 but would take twice as long to construct. This value is still high, but closer to what farmers could afford. Considering that farmers don't have to pay for their own labour and can source their own stone, the amount of actual money that will be required is reduced to 29289 NPR or \$US 325, which brings it under the maximum cost stated in the criteria. It is unclear though how unskilled construction will affect performance of the greenhouse. This scenario will be explored via simulation in Chapter 8.

6.4 Measurement

Various thermal performance data was collected from the greenhouse from December 2009 to March 2010. Total solar radiation on the horizontal plane

outside the greenhouse was measured using an unshielded photoelectric pyranometer (Pacific Systems Pty. Ltd., SolData SPC80 SN 243, spectral range 300-2800 nm). Ambient temperature and relative humidity were also measured with a battery powered data logger (Onset Corp., Hobo H8 Series) located adjacent to the greenhouse. Another battery-powered data logger (Onset Corp., Hobo U12-006 Series and TMC-HD temperature sensors) was used to measure internal greenhouse air and humidity in the middle of the greenhouse. Soil temperatures at 200 and 400 mm depth, and just below the surface inside the greenhouse were also measured with this type of sensor. These devices were cross calibrated against each other at the start of the experiments.

The crops were harvested as needed. In the case of spinach and swiss chard, this was done by removing leaves but leaving the main plant to continue growing. This is the traditional method and prolongs the harvest. The harvest crops were weighed according to their type on the day they were harvested and recorded in a log.

6.5 Results

The data collected has been analysed to reveal key greenhouse performance data over the winter period, in terms of indoor conditions and crop production.

6.5.1 Growing conditions

Figure 48 illustrates the typical daily behaviour of the greenhouse in terms of temperature and relative humidity in January. Overnight minimum temperatures range from 2 – 3°C and occur at approximately 7 am each day. On average, between sunset and sunrise, the greenhouse air temperature is approximately 3.5°C above the outside ambient temperature. An exception to this is on the 17 January when the greenhouse vents were left open all night and the inside temperature was equal to the ambient temperature.

The sun first shines on the greenhouse at approximately 9.30am in winter, when it is no longer in the shadow of a nearby mountain. The outside ambient and greenhouse air temperatures start to rise soon afterwards. During the daytime the average greenhouse air temperature is approximately 14.3°C above the outside air temperature, with a peak of between 32 - 40°C at approximately 2.30 pm. The exception to this is on the 13 January when the weather was cloudy and solar radiation low. On this day, the average temperature difference between

inside and outside is 5.5°C. The soil temperature at 250mm below the surface ranges between 9 -12°C. On a sunny day, the average greenhouse relative humidity is nearly 51%, approximately 15 percentage points above the ambient level. Horizontal solar radiation on a sunny day is around 13 MJ m⁻².

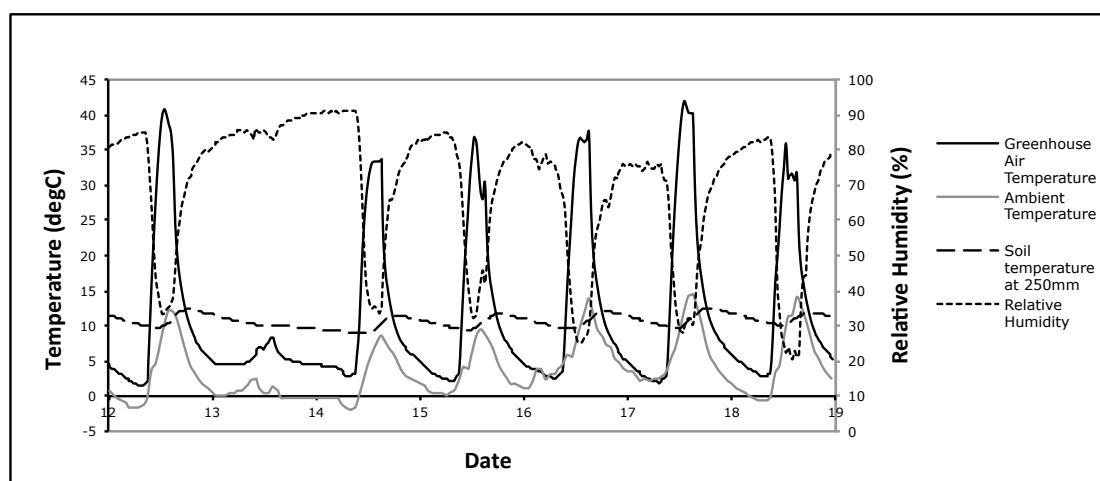


Figure 48 - Typical daily greenhouse temperature and relative humidity levels in January 2010.

It can be seen that the greenhouse daytime air temperatures are very high, exceeding the recommended limit of 32°C. The overnight air temperatures drop below 10 °C overnight and on cloudy days, but do remain above zero. The soil temperatures are sufficient for seed germination for most crops because they are within the range of 7 - 24°C. Relative humidity is high but does not exceed 90%, therefore satisfies the humidity criterion. These results suggest that the thermal mass incorporated into the greenhouse structure is not effective enough in regulating greenhouse air temperatures. Although vegetables could be produced in these conditions, improving the thermal performance of the greenhouse, such as reducing the maximum daily temperature and increasing the overnight minimum, would possibly be beneficial to crop growth and productivity.

6.5.2 Crop production

The crop production results were quite varied according to type, with some crops growing better than expected and others not germinating successfully. This contradicts the performance results stated in Section 6.5.1, since soil temperatures were considered to be adequate but air temperatures were not.

Yield figures in kg/m²/month were calculated based on the harvested amount per square metre of bed area and the time required from seed planting in late spring until the end of the winter period (since for this entire period, no other crops could be grown in that greenhouse bed). Cauliflower grew particularly well, with yields more than double what was expected based on field values (listed in Table 27). Cauliflower is known to be sensitive to temperature and water stress, and also prone to pest infestations (DAFF 2011). In field trials in India, Karnataka (2011) found that the initiation of curds occurred earlier in greenhouses than in outside field trials. This fact, along with the lower chance of water stress and pest infestation due to the protected environment, could explain the higher yields compared to the field values found in literature.

Spinach also grew well, but did not quite reach the yield values achieved in other high altitude greenhouses. This is potentially because spinach is known to be a crop suitable to cooler conditions and maximum temperatures in the Humla greenhouse were approximately 5°C higher than in the Ladakh greenhouse (Rozis & Guinebault 1996) and higher than 32°C, the upper temperature boundary for most crops. Carrot and swiss chard crops failed to germinate initially, until local staff changed the operating procedures and kept the vents closed to increase the air temperature until germination took place. Some carrot and swiss chard crops were harvested, but yields were low. For carrot, this is believed to be partially due to the poor quality of the soil, because carrot crops generally require soil with good fertility to form tubers (Bennett 2000). In addition to this, neither swiss chard or carrot respond well to acidic soils (DAFF 2008), which are typical in mountain areas in Nepal (Pariyar 2008). Table 27 shows the average yields per square metre per month achieved from crop data collected over two successive winter seasons.

Table 27 – Expected and actual yields of greenhouse crops.

Crop type	Expected Yield (kg/m ² /month)	Actual Yield (kg/m ² /month)
Cauliflower	0.67	2.16
Spinach	2.00	1.37
Swiss chard	2.00	0.48
Carrot	3.4	0.14

These values were used to update the linear programming model used for crop selection (outlined in Chapter 5) to explore the effect that the actual greenhouse

production would have on improving nutrition. Assuming a total growing area of 25 m², the best overall nutrition improvement could be achieved with 5 m² planted with cauliflower and 20 m² planted with spinach, based on the highest MAR value (Table 28). It should also be noted that the other vegetables were not allocated growing area by the linear programming simulation, indicating that their yield values combined with their nutrient content were not comparatively high enough to contribute significantly to the objective function.

Even though the allocation of 5 m² planted with cauliflower and 20 m² planted with spinach gives the highest MAR value, realistically the combination of 10 m² with cauliflower and 20 m² with spinach is considered to be a better overall result. For this combination, the MAR is still high but there are more balanced proportions of each vegetable, corresponding with a daily portion size per member of 144 grams for cauliflower and 136 grams for spinach. Although not explicitly measured in the criteria, this would also be more palatable since the vegetable curry would have more than one ingredient.

Table 28 – Simulation results showing nutrient levels for combination of existing produce (rice daal and roti), greenhouse produce (spinach, cauliflower) for different growing area proportions of spinach and cauliflower.

Growing Area Cauliflower (m ²)	Growing Area Spinach (m ²)	Nutrient adequacy ratios (NAR) (% RNI)						MAR (%)
		Protein	Iron	Zinc	Vitamin A	Vitamin C	Energy	
0.0	0.0	76.6	68.4	51.7	0.0	0.0	60.5	42.9
25.0	0.0	92.9	74.2	56.7	0.6	379.9	64.4	54.1
20.0	5.0	93.0	81.2	58.6	43.1	314.6	64.1	62.7
15.0	10.0	93.1	88.2	60.4	85.6	249.2	63.8	71.2
10.0	15.0	93.1	95.3	62.3	128.1	183.9	63.5	75.1
5.0	20.0	93.2	102.3	64.1	170.6	118.5	63.3	76.6
0.0	25.0	93.3	109.3	66.0	213.1	53.1	63.0	70.3

Figure 49 shows the improvement compared to the average baseline winter nutritional intake scenario for a family determined in Chapter 5 (see Figure 25).

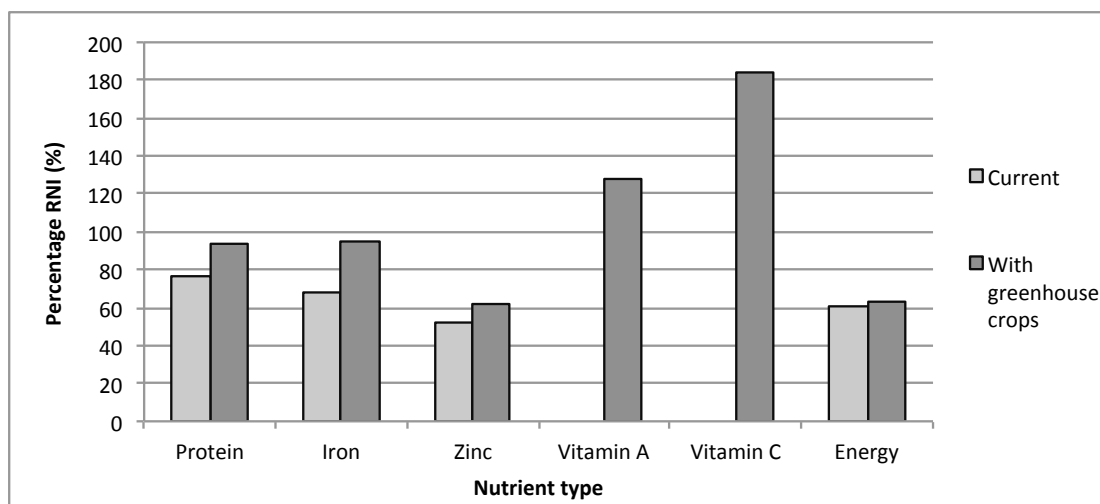


Figure 49 – Comparison of nutritional status with and without greenhouse produce over the winter period from January to March.

These results show that the nutritional criteria can be largely met with current produce, even though the performance criteria are not entirely satisfied (soil temperatures are within the recommend range but air temperatures are outside the recommended range). Other aspects of “appropriateness” have not been met, however, since the cost of the greenhouse is high. Although the initial aim of the research was to use simulation to improve the greenhouse performance to increase crop production, this combination of results suggests that improvement via simulation would be more beneficial if focused on reducing cost, while maintaining the same performance.

6.6 Summary and Conclusion

In this chapter, the design selection, construction process and results for the experimentation process were presented. These included temperature and humidity data, crop production and overall cost of construction. These results were discussed in relation to the appropriateness, performance and nutrition criteria.

The experimental results show that the GERES design can be constructed and operated in Humla, as long as some design modifications are made, partially satisfying appropriateness criteria. The main features of the walled design include double dry-stone masonry walls with a thickness of 30cm each and filled with straw insulation; a double layer of UV stabilised polyethylene for the glazing to increase night temperatures and additional vents in the front corners of the

glazed surface to counteract any increase in day temperatures; a roof that was made from layers of wooden planks, straw, earth and plastic sheeting and slightly shorter than the original design due to restrictions with local material; and a narrow footprint along the north-south axis due to the size of the UV plastic sheets available. This factor, along with the thicker walls, reduced the growing area compared to the Ladakh design.

Performance criteria were not entirely satisfied, with daytime maximum and night time minimum temperatures of 40°C and 2°C respectively, but the type and amount of crops produced were found to adequately improve nutrition requirements. Nutrient requirements were met for vitamin A (128% RNI) and vitamin C (184% RNI), mostly met for protein (93% RNI) and iron (95% RNI). The results for zinc and energy did not show much improvement at 62% and 63% RNI respectively. Overall, the MAR was 75%. The high cost results show, however, that this design is not ideal. Although the costs could have been inflated due to this being a development project with foreign involvement, this still suggests that changes to the greenhouse construction and operation that maintain current performance while decreasing costs would make this design more appropriate for use in Humla. In Chapter 8, a simulation model will be developed to test different scenarios to see if this aim can be achieved.

6.7 References

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Chapter 7

Solar Dryer Design Selection, Construction and Experimentation

7 Solar Dryer Design Selection, Construction and Experimentation

In Chapter 2, a significant imbalance between the food available throughout the year in Humla was identified. Typically vegetables and fruit are abundant during the short summer, but non-existent during winter. As presented in Chapter 6, the greenhouse can be used to produce fresh vegetables in winter to contribute to addressing this imbalance. How the solar dryer produce will contribute to answering the research question, whether greenhouses and solar dryers can improve food availability, is to preserve excess crops from the summer, so that they can be stored and then consumed during winter.

In Chapter 5, apples were identified as a suitable crop for the solar dryer due to their nutritional content and local availability. They are also not currently preserved in any way. When investigating the best distribution of crops to address nutrition criteria with the linear programming model, it was found that the contribution of apples to the overall nutrition improvement was small compared to that of the greenhouse. However, the amount of apples that could be theoretically dried was based on assumptions related to drying and labour time that need to be verified with experimental data.

The purpose of this chapter is to outline the selection and construction of an appropriate solar dryer design and to assess the performance of that dryer through experimentation, particularly in comparison to traditional sun drying. The aims of the experimentation process are to determine that the selected design can be built and to determine that the safe storage moisture content can be reached. A further aim of the experimentation process is to collect data to validate a simulation model and to establish a baseline from which improvements can be made.

In Section 7.1, the solar drying process is outlined including the main factors that contribute to effective drying, followed by an outline of the criteria for design selection and performance. In Section 7.2, existing high altitude dryer designs are considered and compared, taking into account local constraints such as cost, material and resource availability. This is followed by a description of the construction process and cost of the chosen design in Section 7.3. In Section 7.4,

the experimentation method is outlined, followed by presentation of the results in Section 7.5.

7.1 Solar drying process

Drying is simply the process of moisture removal from a product. It can be performed by various methods for a variety of different substances from solids to gases and even liquids (Hall 1980). Thermal drying is the method most commonly used for drying agricultural products. The basic principle of crop drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time. It is a dual process of heat transfer to the product from the heat source and mass transfer of moisture from the interior of the product to its surface, and then from the surface to the surrounding air (Ekechukwu & Norton 1999). In the case of solar drying, the heat is provided by solar energy. The main factors that affect the drying process are explained below.

7.1.1 Moisture content

The moisture content of any product describes how much moisture and how much dry matter (what is left when all the water is removed) are present in the product at any particular time (Fuller 1998). The moisture content can be defined in two different ways: wet basis and dry basis. Wet basis (wb) is the ratio of the weight of water in the product at any time compared to the total weight of the product at that time. Dry basis (db) is the ratio of the weight of the water in the product at any time compared to the weight of the dry matter (Fuller 1998). Although wet basis is conceptually easier to understand, dry basis is most commonly used when analysing the drying process in more detail, so for the purposes of this investigation, dry basis (db) will be used.

The values of moisture content that are of interest when drying a crop are the initial, final, equilibrium and critical moisture contents. Initial moisture content not only describes the original water content of the crop, but is also important in determining a suitable drying method and is used to calculate the moisture content at later stages of the drying process. Final moisture content is compared to the safe storage moisture content of the particular crop to determine if it is at a point below which crop deterioration will not occur under certain storage conditions.

Equilibrium moisture content is important in understanding the drying process. Any crop has a characteristic water vapour pressure (related to water content) at a particular temperature and moisture content. This determines if the crop will absorb or desorb moisture on exposure to air. Equilibrium moisture content of a hygroscopic product refers to the moisture content of the product after it has been exposed to a particular environment for an indefinitely long period of time (Ekechukwu 1999) (see Section 7.1.2 for further explanation of hygroscopic and non-hygroscopic materials). At this moisture content, the vapour pressure exerted by the moisture held within the product equals the vapour pressure of the surrounding air. An equilibrium condition is reached where the rate of moisture desorption by the product equals that rate of absorption from the environment and the net moisture exchange is zero. The relative humidity of the surrounding air at this condition is known as the equilibrium relative humidity. If the surrounding air is then replaced by air of a lower vapour pressure (i.e. with lower relative humidity than equilibrium relative humidity), a vapour deficit is created and the crop will continue to desorb moisture to the air. The main principle of dryer design is to create a microclimate around the crop inside that has a lower vapour pressure than outside conditions, for faster drying and removal of a greater percentage of moisture. This is achieved through a combination of heat and airflow.

The critical moisture content is the minimum moisture content at which the minimum rate of free water moisture migration from within the product to the surface equals the maximum rate of moisture evaporation from the surface (Hall 1980). The concept of critical moisture content will be discussed further in Section 7.1.2 in reference to drying rates.

7.1.2 Drying rates

Agricultural products differ from most other materials dried frequently, such as sand and stone dust. These latter materials are known as non-hygroscopic and moisture within them is “loosely” held and regarded as unbound (Howe 1980). For hygroscopic materials, the moisture held within them is usually bound moisture, such as moisture trapped in closed capillaries; the water component of juices held by surface forces and unbound water held within the material by the surface tension of the water itself (Howe 1980).

When a product is heated at constant moisture content, its vapour pressure increases, resulting in moisture movement to its environment (assumed to be at a lower vapour pressure). The rate of moisture flow is only approximately proportional to its vapour pressure difference with the environment because of the crop resistance to moisture flow. Agricultural products generally have both free and bound moisture, resulting in two main drying rate regimes: constant and falling rate periods (Figure 50).

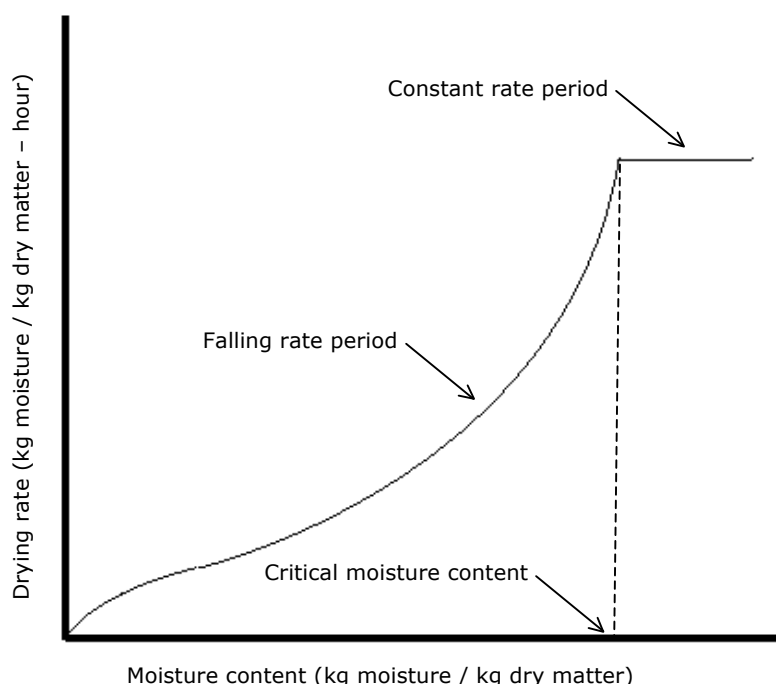


Figure 50 – Typical drying rate curve for a food product (based on diagram from Heldman & Hartel 1997 – pg. 186)

During the constant rate period, drying takes place from the surface of the product and is simply the evaporation of free water on the crop surface. The rate of moisture removal during this period is mainly dependent on the surrounding conditions and only affected slightly by the nature of the product (Ekechukwu 1999). For this reason the drying rate is relatively constant if conditions are constant. Factors for maintaining effective drying include maintaining good airflow and keeping the relative humidity of the dryer air as low as possible with moderate air temperature (Fuller 1998). Lower ambient pressure, as is experienced at high altitudes, can also increase the drying rate during the constant rate period since the vapour pressure of the air is reduced, increasing the vapour pressure difference.

The falling rate period commences once the critical moisture content is reached and all free water has evaporated. During this period, drying rate is largely dependent on the rate of diffusion of moisture from within the product to the surface, which is limited by mechanisms of internal mass transfer. These mechanisms are not well understood and the drying rate is often difficult to predict. Air movement, relative humidity and pressure have little influence on the drying rate (Heldman & Hartel 1997). Prominent diffusion mechanisms occurring during this period, such as liquid diffusion and thermal flow, depend on temperature and thickness of the product. Increased temperature increases diffusion rates and thickness affects how far the moisture needs to migrate to the surface. Although vapour pressure diffusion also occurs and can influence drying rates, it is not the driving force like it is during the constant rate period. Relative humidity will, however, affect the drying process if it is sufficiently high so that the air and the product reach equilibrium and drying no longer occurs.

The drying rate decreases with decreasing moisture content during the falling rate period. This is due to three reasons. Firstly, physical changes occur in the product which reduce the mobility of water molecules (Heldman & Hartel 1997). Secondly, as moisture content of the crop decreases, the crop temperature approaches that of the drying air. This causes a reduction in heat transfer, since the rate of heat transfer from the surrounding air is proportional to temperature difference. Thirdly, reduction in moisture content reduces the vapour pressure difference between the crop and the surrounding air, reducing mass transfer and the drying rate.

For fruits and vegetables, the initial moisture content is usually above the critical moisture content, so the drying of these products takes place within both the constant and falling rate periods (Ekechukwu 1999). It has however been found that the constant rate period of many fruits and vegetables is short, so most of the drying occurs in the falling rate period. This means that a moderate to low airflow, together with the highest safe temperature should give optimum drying conditions (Fuller 1998).

7.1.3 Temperature

The optimum drying temperature varies depending on the crop type and on the drying period (constant or falling rate). It was mentioned that high temperatures

are beneficial in the falling rate period because they increase internal diffusion processes, but temperatures that are too high can have a detrimental effect for a number of reasons. Firstly, high temperatures may cause the product to burn and cause unpleasant discolouration and taste, or result in caramelisation of the sugars in the product. High temperatures at an early stage in the drying process may also cause hardening of the surface of the product. This not only effects the texture, but will also impede the movement of moisture to the surface (Fuller 1998). Carrin and Crapiste (2009) indicate that severe surface hardening occurs for apples when crop temperatures reach 60-65°C. In general, most horticultural crops can be successfully dried at air temperatures of 50-60°C (Fuller 1998).

Temperature is determined by the overall rate of heat transfer to the product. For solar drying, this can be calculated with Equation 12. It must be noted that radiation from the interior surfaces of the dryer also contributes to increasing crop temperature but is very small compared to the effects of the other factors so has not been included.

$$\begin{aligned} Q_{total} &= Q_{solar} + Q_{convection} - Q_{evaporation} \\ &= I_{eff} \alpha_{crop} A_{crop} + h_{conv} A (T_{air} - T_{crop}) - \dot{m}_w \Delta H_v \end{aligned} \quad \text{Eq. 12}$$

where:

- I_{eff} = effective incident solar radiation on crop surface
- α_{crop} = solar absorbance of crop surface
- A_{crop} = area of crop surface exposed to solar radiation
- h_{conv} = convective heat transfer coefficient
- A = surface area of crop exposed to air
- T_{air} = air temperature
- T_{crop} = crop temperature
- $\dot{m}_w$ = rate of moisture loss
- ΔH_v = latent heat of vaporization

The convective heat transfer coefficient is a function of the mass flow rate, G , of the surrounding air. According to Fellows (1990), it can be calculated with the following equations, depending on whether the flow is parallel or perpendicular to the surface of the product:

$$h_{conv,parallel} = 14.3 G^{0.8} \quad h_{conv,perpendicular} = 24.2 G^{0.37} \quad \text{Eq. 13}$$

Equation 12 and 13 show that the rate of heat transfer is influenced by the temperature of the surrounding air, incident solar radiation, mass flow rate, crop surface area and rate of moisture loss, many of which are interrelated. In the constant rate period, the rate of moisture loss is determined by the vapour pressure difference, while in the falling rate period it is determined by the rate of moisture diffusion to the surface. In the dryer, the temperature of the surrounding air will be influenced by solar radiation and airflow. Crop surface area will be affected by the size of the drying samples and rate of shrinkage during the course of drying. For this reason, airflow, size and shrinkage will be discussed in more detail in the following sections.

7.1.4 Airflow

The rate of airflow through the dryer influences the mass flow rate, which can have contradictory effects on the rate of heat transfer through convection. Higher mass flow rates will increase the convective heat transfer coefficient and increase the rate of heat transfer via convection. Higher flow rates will also, however, potentially reduce the temperature of the dryer air due to increased infiltration with the ambient air (if the dryer is working as it should, with the aim being to improve drying conditions compared to that of traditional sun drying, then it is assumed that the temperature of the ambient air would be lower than that of the dryer air). This would reduce the temperature difference between the crop and air, reducing the rate of convective heat transfer. No airflow at all would also stop the drying process, since moisture on the crop surface would not be removed and would prevent further moisture from migrating from the centre of the produce. Therefore it is necessary to achieve sufficient airflow to allow for convective heat transfer and moisture removal, but not so much that the dryer air temperature is reduced.

7.1.5 Size and shrinkage

The size of the pieces being dried is important for both the constant and falling rate periods in the drying process. In the constant rate period, moisture is evaporated from the exposed surface area of the crop. Since the combined surface area of a lot of small pieces is greater than the surface area of one larger piece of the same weight, smaller pieces will dry faster. In the falling rate period, moisture migrates from the centre to the edges of the pieces. With smaller pieces, the distance from the centre to the edges is less, so drying will again be

faster (Fuller 1998). Smaller pieces, however, can result in smaller batch sizes and lower loading ratios in the dryer. The increased drying rates for small pieces needs to be considered against the potentially higher dried crop output with bigger pieces.

As crop samples dry, they will also decrease in size. This factor needs to be considered for direct solar dryers since the area of the crop is proportional to the amount of solar radiation it can absorb. This aspect relates to crop temperature and the subsequent drying rate. Types of dryers will be discussed further in Section 7.2.

7.1.6 Design selection and performance criteria

Aside from the nutritional criteria established in Chapter 5, the design selection and suitability of the solar dryer will be determined by the appropriateness criteria and performance criteria. Like that for the greenhouse, the appropriateness criteria stipulate that the solar dryer must be built largely with local materials and expertise, using local resources and suit local conditions and cultural structures. Specifically, the latter refers to the operation and scale of production. Research from Sanders (2010) states that technologies are best managed at a household level, which implies small scale solar dryer production. This also means however that production is limited to that which can be achieved within available labour time constraints.

For the solar dryer, a balance is required between performance and cost to ensure that the solar drying process is superior to that of traditional sun drying, but also affordable for the local community. In terms of performance, it is necessary that the solar dryer can dry the samples to safe storage moisture content at a faster rate than that of sun drying. Although solar drying has other advantages over sun drying, a faster drying rate would be the most likely factor to encourage investment in the technology. For apples, safe storage moisture content is 0.28 (db) (UNECE 1998). It is also necessary that uniform drying to safe storage moisture content be achieved in a short enough period before the samples spoil or grow mould. Based on the previous discussion of the solar drying process related to drying rates this will most likely be achieved with dryer air temperatures between 50-60°C. In addition to this, crop temperatures should not exceed 60°C to prevent surface hardening and damage to the product.

Affordability of the solar dryer will be determined based on a comparison with the cost of other small technologies in use in the area. As mentioned already in Chapter 6, most families are willing to pay \$50 for minor technologies such as improved cooking stoves, distributed by RIDS Nepal at \$100 each with a 50% subsidy (RIDS Nepal 2012), since they reduce the amount of firewood required for cooking and the labour involved in collection. This amount is high compared to other appropriate technologies, but is justified in that it is one that will provide benefits on a daily basis. Although a solar dryer is operated periodically through the year, it can be argued that it also provides benefits on a daily basis because the food it produces can then be consumed daily. It is therefore assumed that a family would be willing to invest the same amount in a similar minor technology like a solar dryer, if the performance was sufficiently better than current drying methods.

7.2 Design selection

This section presents and discusses three different solar dryer designs used in Mustang, another high mountain region in Nepal, and their applicability in Humla. Currently, three different solar dryer designs are used in the Lower Mustang region. These are: a large scale tunnel dryer, indirect solar cabinet dryers similar to those already used in Humla, and small wooden “Brace” direct box type solar dryers. Examples of these designs are shown below in Figure 51.



Figure 51 - Solar dryers in Lower Mustang: direct box type; indirect cabinet; large-scale tunnel dryer (photos – S Candy).

The large-scale, community managed tunnel dryer is considered to be unsuitable for use in Humla for two main reasons. Firstly, it is suited to areas where apples are grown in plantations and is too large for the scale of agricultural production in Humla. Secondly, even if the apple production was large enough to warrant such

an investment, it was also discussed in Chapter 3 that community managed initiatives have not been successful in Humla in the past, since they do not suit cultural structures and the traditional division of labour. Smaller, family-based initiatives are considered to be more suitable.

The indirect solar dryers used in Mustang are said to work well and are a suitable size for small scale drying. They differ from those used in Humla by the fact that they are fitted with an external electric fan to improve the airflow. Again, however, there are two main reasons why these design would not be suitable for Humla. Firstly, unlike in Mustang, access to electricity resources is unreliable in Humla. Without the electric fan, these cabinet dryers would be very similar to those already used in Humla (discussed in Chapter 3). These designs were evaluated by Fuller et al. (2007) who concluded that they were not much better than sun drying. A solar powered fan could be added, but this would significantly increase the initial cost of the technology. The cost of the indirect solar dryers currently used in Humla is around 30,000 NPR or \$US 330, which is already significantly higher than the \$50 considered to be affordable in the criteria. In addition to this, these dryers would need to be manufactured elsewhere and transported in pieces by plane and then on foot to villages. The dryers currently used in Humla employ this process, which has proven to be costly and difficult, and at times results in the parts being damaged in transit.

The direct box type solar dryers are the simplest of the three designs used in Mustang and the most widespread in use (Joshi & Gewali 2002). They are suitable for small-scale producers because they are easy and inexpensive to construct with local materials, simple to use and produce a reasonable dried product. In most cases, they are also naturally ventilated and can be used in areas where electricity is not available. The cost of these dryers in Mustang is not specified in the literature, but based on the size and materials required, it is expected that it will cost around \$50. For these reasons, the direct box type design was considered to be the most suitable for use in Humla.

7.3 Construction

Two versions of a direct wooden dryer were constructed and tested in Humla. Initially, a design similar to that developed by Bena and Fuller (2002) was trialed (Figure 52 – left). It was tested in Humla in March 2008 and September 2008. In the earlier test in March, samples were successfully dried within 2-3 days, similar

to results achieved by Fuller in 2007. In September, however, inclement weather prevented any successful drying tests being completed. The latter is a more significant result because September coincides with the apple harvest period. Based on measurements taken, there was negligible airflow in the dryer, which suggested that a modification to the design was required. Following this, a revised design was developed by the author in 2009 based on small metal box dryers that are used in Kathmandu (Figure 52 – right) and adapted for Humla by changing the main construction material to wood, and using plastic sheeting for the glazing.



Figure 52 – Initial solar dryer design; Kathmandu solar dryer design (Photos - S Candy).

An example of the new design was constructed for preliminary testing in Melbourne in January 2009 and then another was constructed on-site in Humla in September 2009 (Figure 53). In Humla, a local carpenter was contracted to build the dryer out of locally available wood. Plastic film was used for the glazing and wire mesh for the vents and trays, both of which are available in the market in the main village and easy to transport to villages. It was necessary to import wood varnish from Kathmandu and adhesive foam door seals from Australia, although it may be possible to source these in Kathmandu also.



Figure 53 – Construction of the direct box type solar dryer in Humla (Photos – S Candy).

The solar dryer has wooden sides, base and back, with a glazed front slanted at 30° to the horizontal. It has an inlet at the bottom front and an outlet at the top back and three trays distributed over two tray levels. The top tray and the bottom rear tray are the same size to enable easy tray rotation if necessary for even drying. The dimensions of the dryer are shown in Figure 54.

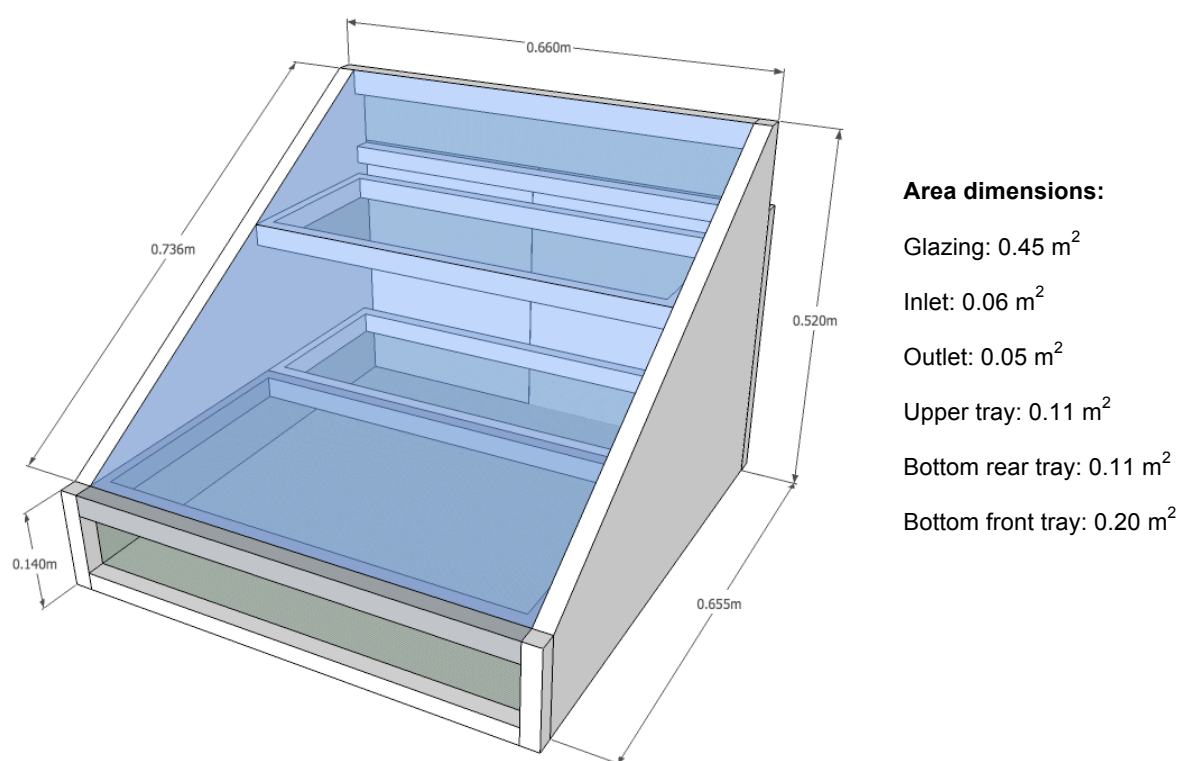


Figure 54 – Scale drawing of solar dryer with dimensions.

Three days were required for construction of the solar dryer. Taking into account labour and materials, the dryer cost approximately 5000 NPR (approximately \$US 55). This is significantly less than the cost of the existing solar dryer design which

costs 30,000 NPR to construct and a further 7700 NPR to transport to Humla (Fuller, Aye & Zahnd 2007). It is also comparable to the cost of other small-scale appropriate technologies in operation in Humla, suggesting that the solar dryer would be affordable for local people.

7.4 *Experimental Method*

The selected solar dryer design was constructed and tested in Humla in September 2009. Tests had also been performed prior to this with an identical dryer in March 2009 in Melbourne, Australia. Figure 55 shows the solar dryer experimental set-up on the roof of the RIDS Nepal field office in Darapori, Humla. The sun drying samples are on the tray to the left of the dryer, the devices measuring ambient temperature, humidity and wind are mounted on the pole to the right of the dryer and the device measuring solar radiation is on the platform in the far right of the picture.



Figure 55 - Solar dryer experimental set-up in Humla (loaded test) (Photo – S Candy).

The solar dryer was tested in both the unloaded and loaded condition, with four tests each. The purpose of the unloaded tests was to produce data to validate assumptions made in the simulation model related to the construction of the solar

dryer, such as the thermal properties of the walls, and glazing and to determine airflow characteristics. The purpose of the loaded tests was first to evaluate the principal dryer characteristics, including capacity, drying times, uniformity of drying and shrinkage. The overall thermal efficiency was also investigated as a performance measure to provide a baseline for dryer performance. An important comparison was also made between solar drying and traditional sun drying. Although solar drying has advantages over sun drying in that the product is protected from dust, insects and sudden rainstorms, improved performance would be necessary to justify investment in a dryer. In order to analyse performance and for the purposes of modeling, the trays and sections (or zones) of the dryer were labeled as shown in Figure 56.

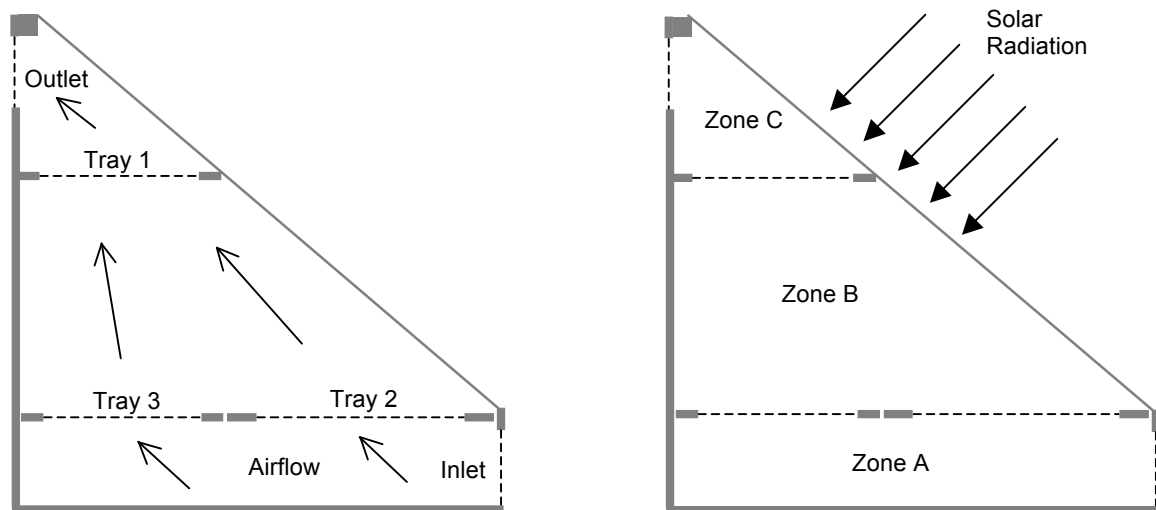


Figure 56 – Diagram of solar dryer showing tray position, airflow and section zones.

The test procedure and instrumentation were slightly different for the unloaded and loaded tests. Figure 57 below shows the experimental set-up for the solar dryer tests, including the position of temperature and humidity sensors. Further explanations about measurements are listed below. Since the aim of the humidity measurements was to measure changes in absolute humidity for evaporation calculations, humidity sensors were not used for the unloaded tests.

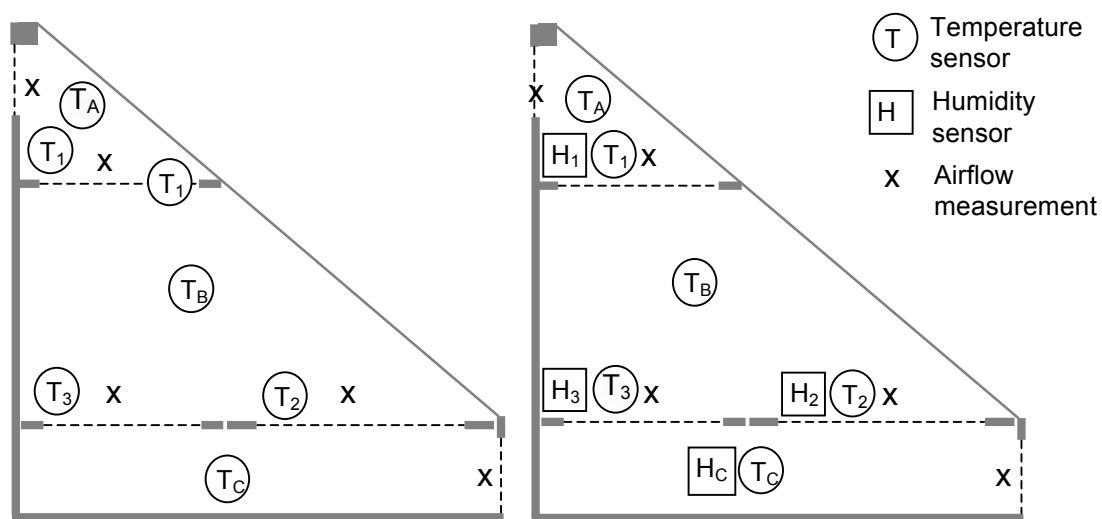


Figure 57 – Position of sensors for unloaded (left) and loaded (right) tests (not to scale).

7.4.1 Ambient conditions

Total solar radiation (sum of direct and beam radiation) was measured on the horizontal plane and in the plane of the glazing (30°) using a photoelectric pyranometer (Middleton & Co Pty Ltd – when testing in Australia & SolData SPC80 SN 243 – when testing in Humla). The in-plane measurement is necessary to account for reflection from the ground and nearby surfaces. Values were recorded every 15 minutes, and consisted of an average of instantaneous values measured every minute over the previous period. Ambient temperature, humidity and wind-speed were measured using a weather station (LaCrosse WS-2355).

7.4.2 Dryer Temperature and Humidity

The air temperature inside the dryer was measured and recorded every 10 minutes above each tray and in the middle of each zone (Figure 57). These temperature measurements will be used to verify the relationship between the ambient conditions and the conditions inside the dryer according to the heat and mass balance equations. Fruit temperature measurements were also taken in the middle of each tray over the same intervals.

Relative humidity measurements were recorded during the loaded tests inside the dryer in four positions (Figure 57 - right). The first measurement was taken in Zone C at the bottom of the dryer, the second and third above each of the two lower trays (Hobo U12 data logger) and the fourth measurement was taken

above the top tray just below the outlet of the dryer (Logit LTH data logger). The inlet air humidity was assumed to be the same as the ambient value. The first and fourth measurements will show the increase in absolute humidity in the dryer air as it moves from inlet to outlet, and the second, third and fourth will show the increases in absolute humidity at each tray level.

A combination of sensors were used to measure temperatures and humidity including K-type and T-type thermocouples connected to a Datataker DT 50 data logger, a Hobo U12 data logger and a Logit LTH data logger. Radiation shields were placed around the sensors measuring air temperatures to prevent additional heating from direct radiation. Table 27 lists and describes the equipment used for the testing and Table 28 shows which instruments were used to measure each variable. For the Humla tests the measuring equipment was arranged slightly differently and the measurements taken with Hobo data-loggers and TMC6-HD sensors instead of using the DT50 and thermocouples. This has been indicated in brackets in the table. All devices were cross-calibrated against each other at the start of the experiments. The average error between temperature measurements was only 0.7°C, with the largest instantaneous error being no more than 1.1°C. The average error between relative humidity measurements was 1.9 percentage points, with the largest instantaneous error no more than 2.5 percentage points.

Table 29 - Equipment List.

Model	Description
Hobo H8	Battery powered data logger that measures air temperature and humidity
Hobo U12-012	Battery powered data logger that measures air temperature and humidity with one external temperature sensor input.
Hobo U12-006	Battery powered data logger that measures temperature with four external temperature sensor inputs.
TSI VelociCalc 8350-1	Hand held hot wire anemometer
TMC6-HD temperature sensors	Used with Hobo H12-012 and H12-006 to measure air temperature.
Datataker 50	Battery powered data logger
T / K-type temperature sensors	Used with Datataker 50 to measure air and fruit temperature
LaCrosse WS-2355	Wireless weather station
SolData SPC80 SN 243	Photoelectric pyranometer

Table 30 – Measurements.

Measurement	Location	Instrument
Temperature	Zone A	Datataker 50 – T-type temp. sensor (Hobo H8 logger)
Temperature	Zone B	Datataker 50 – T-type temp. sensor (TMC6-HD sensor)
Temperature	Zone C	Datataker 50 – T-type temp. sensor (TMC6-HD sensor)
Temperature	Tray 1	Logit LTH data logger
Temperature	Tray 2	Hobo U12-012 - TMC6-HD sensor (Hobo H8 logger)
Temperature	Tray 3	Hobo U12-012 data logger
Temperature	Ambient	LaCrosse WS-2355 weather station
Temperature	Tray 1 - Fruit	Datataker 50 – T-type temp. sensor (TMC6-HD sensor)
Temperature	Tray 2 - Fruit	Datataker 50 – T-type temp. sensor (TMC6-HD sensor)
Temperature	Tray 3 - Fruit	Datataker 50 – T-type temp. sensor (TMC6-HD sensor)
Humidity	Tray 1	Logit LTH data logger
Humidity	Tray 2	Hobo H8 logger
Humidity	Tray 3	Hobo U12-012 data logger
Humidity	Zone C	Hobo H8 data logger
Humidity	Ambient	LaCrosse WS-2355 weather station
Airflow	Inlet	TSI VelociCalc 8350-1 hand-held anemometer
Airflow	Outlet	TSI VelociCalc 8350-1 hand-held anemometer
Airflow	Tray 1	TSI VelociCalc 8350-1 hand-held anemometer
Airflow	Tray 2	TSI VelociCalc 8350-1 hand-held anemometer
Airflow	Tray 3	TSI VelociCalc 8350-1 hand-held anemometer
Wind Speed	Outside Dryer	LaCrosse WS-2355 weather station
Wind Direction	Outside Dryer	LaCrosse WS-2355 weather station
Solar Radiation (horizontal)	Outside Dryer	Photoelectric pyranometer – Middleton & Co (SolData SPC80 SN 243)
Solar Radiation (@ 30°)	Outside Dryer	Photoelectric pyranometer – Middleton & Co (SolData SPC80 SN 243)

7.4.3 Crop Samples

The apples were sliced and arranged on the dryer trays according to Figure 58. The distribution between the trays amount to 40% of the total load in kilograms on Tray 2, with the remaining 60% divided equally between Tray 1 and Tray 3. The samples were also arranged in the same way across trays for each test (see Figure 58), allowing for similar airflow. Tests were performed with approximate slice thicknesses of both 10 mm and 5 mm. The initial loading ratio was calculated by dividing the total weight of the samples in the dryer by the total area of the trays. The trays were kept in the same position during the tests and

six numbered samples in fixed positions on each tray were monitored more closely to determine if drying varied between trays or across each tray (shown in Figure 58). A separate sun-drying sample tray was set-up next to the dryer for each test for comparison.

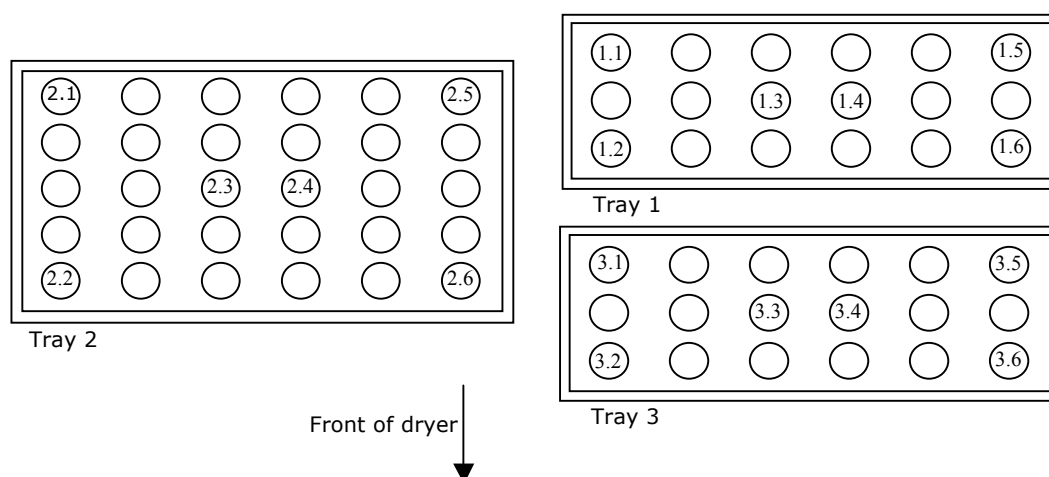


Figure 58 – Arrangement of samples on each tray and labelled positions of six closely monitored samples on each tray.

The mass of the product on each tray was weighed with an electric weighing scale (HF 2000G, A & D Company Ltd) and the subsequent moisture loss calculated. The samples were weighed every two hours in an attempt to determine a drying rate curve. The thickness and diameter of samples was also measured at the end of each drying day to verify the amount of shrinkage. This is considered important since the area of the crop is used in heat transfer calculations.

To compare crop temperature to the drying rate, the simplest method would have been to measure temperature and weigh the same sample over the drying period. Since it was difficult to remove the temperature probe from the semi-dried samples without splitting them, an alternative comparative method was devised to achieve this. Samples of a similar diameter and thickness were chosen and placed in the middle of each tray (labeled 1.3 & 1.4, 2.3 & 2.4 and 3.3 & 3.4 in Figure 58). Crop temperature was measured in the third sample on each tray and the weight and shrinkage was measured closely in the fourth sample.

7.4.4 Airflow

Airflow was measured with a hand-held anemometer (VelociCalc 8350-1, TSI) just inside the inlet and outlet vent. One measurement was taken at one-minute intervals at three points across each vent. Using these values the instantaneous and average airflow rates across each vent were compared against ambient wind speed data in an attempt to find a correlation, and compared against each other to determine if mass flow was constant through the dryer and identify any leakage of air. The flow through and across the trays was measured at one-minute intervals at two points above each tray. Both horizontal and vertical flows were measured by orientating tip of the anemometer in the appropriate direction.

7.4.5 Initial moisture content

The initial moisture content of the apples was determined using the standard oven method, where samples are subjected to drying at temperatures between 70-100°C for various specified times (ISO 7701 1994). In this specific case, the standard used was 70°C $\pm$ 1°C for 6 hours. Since the apples had to be dried in-situ in a remote area and no drying oven was available, a portable electric drying oven was constructed for this purpose. Details about the design of this drying oven can be found in Appendix 1.

7.5 Results

In this section, results from solar dryer experimentation will be presented. This includes results from the determination of initial moisture content, those relating to the performance of the dryer, and potential nutrition improvements from solar dryer produce. The performance criteria state primarily that the solar dryer crop should be dried to safe storage moisture content within a reasonable amount of time so that the crop does not spoil, and at a faster rate than that of traditional sun drying. In addition to this, the dryer needs to be operated within constraints on labour and availability of fresh product. The aspects relating to performance that will be discussed include capacity, drying times and labour; drying rates compared to sun drying and subsequent crop production.

Airflow in the dryer and shrinkage of the drying samples during drying were also measured, as mentioned in Section 7.4. These results were gathered primarily for the purpose of modeling the solar dryer and will not be discussed here because they are not relevant to the conclusions of this chapter.

7.5.1 Initial moisture content

The results from the drying oven tests to determine initial moisture content of the apple samples are shown below in Table 31. The results shown agree with the range of 4.24 – 8.62 (dry basis - db) found in literature (Duke 1992; Meisami-asl et al. 2009; Moyles 1986; Salunkhe 1974; Vesali, Gharibkhani & Hasan-Komarizadeh 2011), however, they do not satisfy the drying standard requirement that duplicate determinations of moisture content should agree to within 0.002 (db). The discrepancy could have been caused by the basic method used to determine the initial moisture content. Since it was not possible to use another method, an average initial moisture content of 5.25 (db) has been assumed. To take into account inaccuracies in this assumption, the apple crop will be considered to be dried sufficiently based on a safe storage moisture content calculated with an initial moisture content of 6.87 (db).

Table 31 – Results of drying oven tests performed in Humla.

Test No.	Initial weight of sample (g)	Final weight of sample (g)	Moisture content (db)
1	21.8	2.76	6.87
2	24.8	4.50	4.37

Unfortunately initial moisture content was not determined for the tests performed in Australia, since the aim of these tests were to test the technology, rather than determine the drying rate of samples. It has been assumed for the rest of the analysis that these samples also had an initial moisture content of 5.25 (db) since most literature sources reviewed stated a value of between 4.88 – 5.67 (db) for apples (Meisami-asl et al. 2009; Moyles 1986; Salunkhe 1974; Vesali, Gharibkhani & Hasan-Komarizadeh 2011).

7.5.2 Capacity, drying time and labour

The capacity of the dryer, indicated by loading ratios, and subsequent drying times and associated labour are important in determining how much produce can realistically be dried over the harvest season. This determines the potential contribution by the solar dryer produce to nutritional improvements. Drying time is also important in that it must be sufficiently short so that drying crops do not spoil before reaching safe storage moisture content of 0.28 (db).

Initially it was intended to complete sufficient tests in Humla for the analysis of the dryer, however erratic weather and intermittent rain events in September

2009 only allowed for one test (Test 4) to be completed. Results were therefore used from prior tests performed in Australia in March-April 2009. From these, successful results were obtained from two of the tests, Test 1 and Test 3. Test 3 was not completed due to bad weather, but the results from the first section of the test could still be analysed. Test 2 was performed with larger samples than either of the other tests, which spoiled on the first day of drying. For this reason, moisture loss and drying time results from Test 2 were not included in the following analysis.

The overall drying times were found to vary depending on loading ratio and ambient conditions. Table 32 summarises the ambient conditions on each of the testing days, including average and peak values. Test 4 was performed in Humla in the northern hemisphere with the dryer facing south to intercept maximum solar radiation, while the remaining tests were performed in Melbourne in the southern hemisphere with the dryer facing north to achieve the same aim. Table 30 has been shaded to make it easier to distinguish between the results of different tests.

Table 32 – Summary of ambient conditions during loaded drying tests.

	Date	Average Solar Radiation MJ/m ² /day	Average Daytime Temp. (°C)	Max. Daytime Temp. (°C)	Min. Daytime Temp. (°C)	Average Daytime Relative Humidity (%)	Average Daytime Wind Speed (m/s)	Average Relative Daytime Wind Direction* (deg)	Peak Daytime Wind Speed (m/s)
Test 1	16/3/09	21.1	28.8	31.7	21.7	31.0	1.7	112.5°	7.6
	17/3/09	14.6	28.9	32.8	24.8	32.8	1.8	157.5°	7.3
Test 2	3/4/09	20.9	27.2	40.1	17.2	44.4	1.7	135.0°	6.1
	4/4/09	20.8	26.2	28.9	17.3	40.3	2.9	45.0°	9.3
Test 3	5/4/09	20.9	27.6	31.8	20.4	35.8	2.7	45.0°	7.0
	6/4/09	13.7	23.1	25.5	21.3	53.7	4.5	22.5°	8.2
Test 4	13/9/09	14.9	19.0	23.0	13.7	59.8	0.9	22.5°	6.5
	14/9/09	17.7	20.7	24.6	13.5	42.1	1.6	0.0°	5.1
	15/9/09	16.6	19.1	22.6	13.5	48.1	1.0	22.5°	3.9
	16/9/09	17.3	19.9	24.8	13.9	43.0	1.4	0.0°	9.2
	17/9/09	19.0	20.9	24.9	13.2	34.5	1.0	0.0°	5.5

* The wind direction is relative to the front of the dryer, 0° - towards the front of the dryer, 90° - towards the side of the dryer, 180° - from behind dryer.

Table 33 shows the average initial sample thickness, corresponding loading ratio, and average air temperature inside the dryer for each test. Only the first day of

Test 1 has been shown because the samples reached safe storage moisture content by the end of the first day. Labour time required to gather and prepare the produce, and operate the solar dryer each day for each test is also included in Table 31. These calculations were based on the assumptions that it takes eight hours to gather 20 kg of apples (0.4 hours/kg) since the apple trees are normally some distance from the house, one hour to prepare the apples (which is the same for different loading ratios because they involved the same number of slices) and 20 minutes per drying day to load and unload the trays at the beginning and end of each day (the samples were taken out of the dryer and inside the house at night to prevent them gaining moisture from the damp night air). These labour values were found to be similar to those estimated in Chapter 5. It must be noted that at no time did the dryer air temperature reach the recommended range of 50-60°C.

Table 33 – Average air temperatures in the solar dryer, labour, loading ratio and number of drying days for each test.

Test	Average initial sample thickness (mm)	Loading ratio (kg/m ²)	Total dryer load (kg)	Labour time required (hours)	No. drying days	Average dryer air temperature (°C)	Average ambient air temperature (°C)
1	6	3.6	1.5	2.8	1	39.1	28.8
3	12	6.2	2.6	4.5	3*	33.0	25.3
4	12	6.2	2.6	5.1	5	32.0	19.9

* Note: Test 3 could not be completed due to poor weather, it is estimated that it would have taken three days to dry the samples to safe storage moisture content.

Figure 59 shows the reduction in moisture content over time for Test 1, Test 3 and Test 4. Each eight hour section on the x-axis represents one drying day. The effective hours after the start of drying indicate the hours that the crop was in the dryer and do not include the hours overnight between drying days. Note that the step changes in the curves are due to the fact that the samples lost some moisture during these overnight hours when they were taken inside.

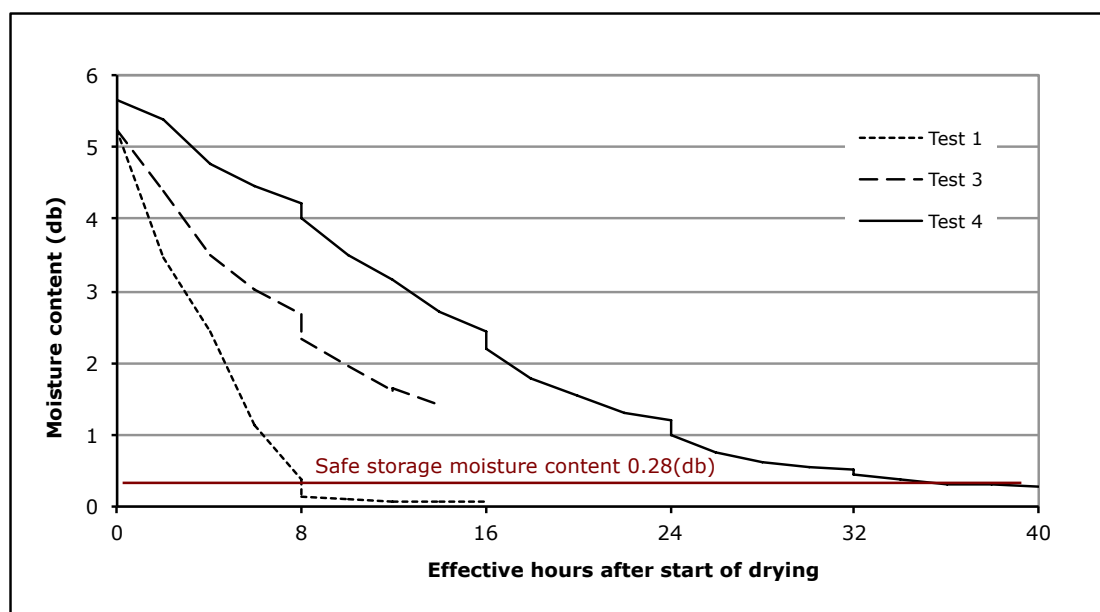


Figure 59 – Average change in moisture content over time for samples for Test 1, Test 3 and Test 4.

Test 1 had the lowest loading ratio (thinnest samples), the highest ambient solar radiation and the highest dryer temperature, so reached safe storage moisture content in eight hours or one day. Test 3 and Test 4 had loading ratios double that of Test 1 but were performed under different ambient conditions (Table 32). Test 4 was performed under cooler, more humid conditions with lower solar radiation at higher altitude compared to Test 3. Test 4 had the longest drying time of five days. If Test 3 had been completed, it is anticipated that it would have taken approximately 24 hours to dry the samples. It is clear that ambient conditions and sample thicknesses both affected the drying times, but it is difficult to predict to what extent based on these results. This will be explored further with an examination of normalized drying rates for each test.

In literature, drying rates for different processes are typically compared by producing drying curves, where the drying rate (change in moisture content per hour) is plotted against moisture content (similar to that shown in Figure 50). This also helps to identify the constant and falling rate periods and predict how much time is required to dry a product. Solar drying tests are different to normal dryer tests in that the external input energy fluctuates depending on the available solar radiation throughout the drying period. The results from the previous section show that this period can extend from one to five days, indicating that significant variation would occur. To compare the results from these solar dryer

tests, an alternative drying curve is instead produced by plotting the change in moisture content per kilowatt hour of solar energy against the moisture content. Solar energy was chosen because it has influence on many aspects of the drying process such as direct solar radiation on the crop; heating of dryer air through radiation on and convection from dryer interior surfaces; and heating of the ambient air entering the dryer. Figure 60 shows the drying curves for each dryer test based on average moisture contents and drying rates. The numbers in brackets in the legend indicate the test number.

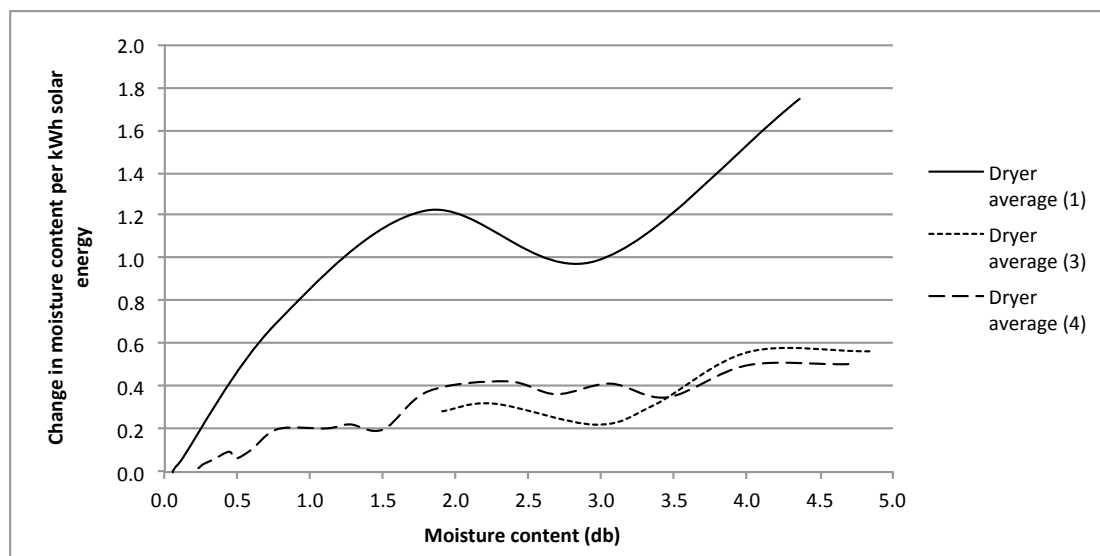


Figure 60 – Drying curves for different dryer tests

These results indicate that a short constant rate period occurs at the beginning of Test 3 and Test 4. It is possible that a constant period also occurred in Test 1, but the measurement interval for moisture content was not small enough for this to be obvious on the curve. This validates the assumption that the majority of drying occurs in the falling rate period for these apple samples. This means that the drying rate is primarily driven by crop temperature rather than the conditions in the surrounding air and vapour pressure difference.

As discussed earlier, Test 1 was performed with a lower loading ratio (thinner samples) than that of Test 3, but under similar ambient conditions, while Test 4 was performed under different ambient solar radiation conditions to that of Test 3, but with the same sample thickness. By considering these aspects, two preliminary conclusions can be drawn. Firstly, by comparing the curve for Test 1 and Test 3, it can be seen that for a given amount of ambient solar radiation,

thinner samples will result in a faster drying rate. In this case it is particularly significant because in Test 1 approximately half the weight of apples were dried to safe storage moisture content in less than half the time compared to Test 3 (1.5 kg/day compared to 0.9 kg/day). Over a given time period, more could be dried in total if the samples were thinner. Due to the erratic weather experienced in Humla during the testing periods, shorter drying times could also allow more tests to be successfully completed in between rain events.

Secondly, by comparing the results for Test 3 and Test 4, it can be seen that for a given sample thickness, improvements in drying rates achieved under one set of ambient solar conditions can be used to predict potential improvements under different ambient solar conditions. This is particularly useful in the context of remote area testing, since results obtained in less remote areas could potentially be used to predict outcomes in remote areas as long as ambient solar conditions were known. For example, these normalized results could be used to predict the efficacy of drying crops later in the year in Humla when the weather conditions are more stable, potentially justifying an investigation into short term cool storage of the fresh produce. This also relates back to the research aims stated in Chapter 4 relating to developing a transferable method that might reduce the amount of time required to test appropriate technologies in remote areas. It should be noted, however, that these conclusions have been based on a small amount of data, so more research is required to confirm it.

7.5.3 Comparison with sun drying and uniformity of drying

The second criteria for solar dryer performance relates to the drying rate of the solar dryer being faster than that of traditional sun drying under the same conditions. In this section the results of solar dried and sun dried samples are compared to establish if this condition has been met.

Figure 61 shows the average drying rates of solar dryer samples and sun drying samples for Test 3 and Test 4, which were performed with the same sample thickness but under different ambient conditions. The sun drying samples from Test 1 were damaged during testing and could not be included. Overall, the average drying rates for the solar dryer are slightly better than that of traditional sun drying under the same conditions.

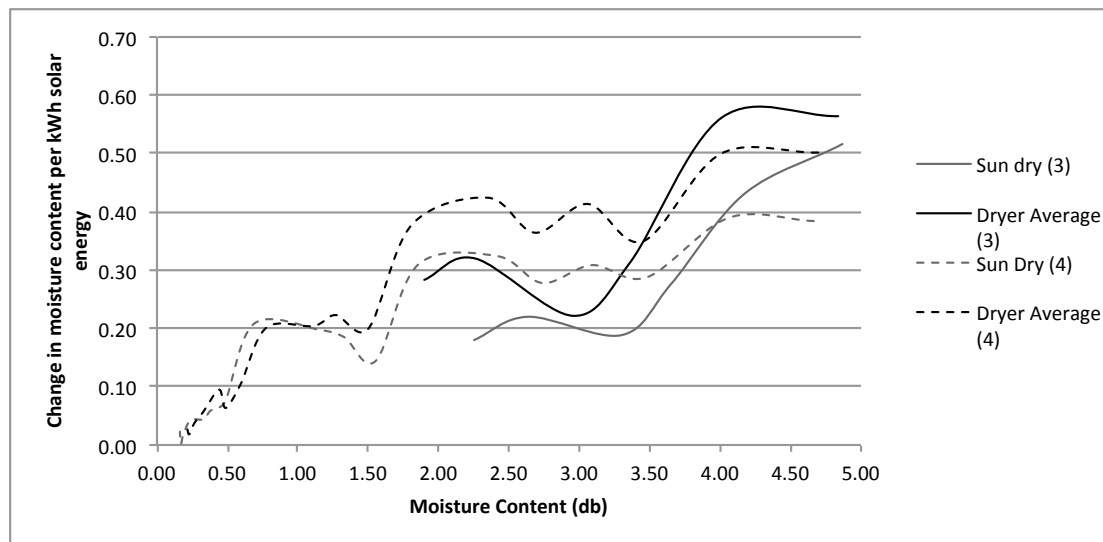


Figure 61 – Comparison of drying rates for the solar dryer and sun drying samples in Test 3 and Test 4.

As established in Section 7.5.2, in Test 3 and 4 the majority of drying takes place in the falling rate period, when the temperature of the crop is the dominant influence on the drying rate. The temperature of the crop is determined from the overall rate of heat transfer that can be calculated with Equation 12. Figure 62 and Figure 63 show the heat transfer rates via solar radiation, convection and evaporation on samples for the solar dryer and sun drying tests respectively for Day 1 of Test 3. It can be seen that heat transfer from solar radiation is slightly less for the solar dryer due to the transmittance factor of the plastic cover, which is assumed to be 80% (Rozis & Guinebault 1996). Heat transfer via convection is larger for the solar dryer than for the sun drying case, suggesting that this is the factor that contributes to the slightly higher drying rate in the solar dryer.

These results suggest that increasing the rate of heat transfer via convection would increase the drying rate in the dryer compared to that of sun drying, since the energy gain from solar radiation is the same or less for solar drying than it is for sun drying. The rate of heat transfer via convection can be increased either by increasing the airflow, to increase the heat transfer coefficient, or by increasing the temperature difference between the crop and the dryer air. Increasing the airflow, however, would also decrease the temperature of the dryer air, possibly decreasing the difference between that and the crop temperature. Increasing the dryer air temperature could be achieved by increasing the absorption of solar radiation on the interior dryer surfaces by painting them a darker colour, which

would then be transferred to the dryer air by convection. This would also depend on airflow through the dryer. An optimum airflow rate could be determined but it would be dependent on other factors such as the temperature of the ambient air and would require further calculations or modelling.

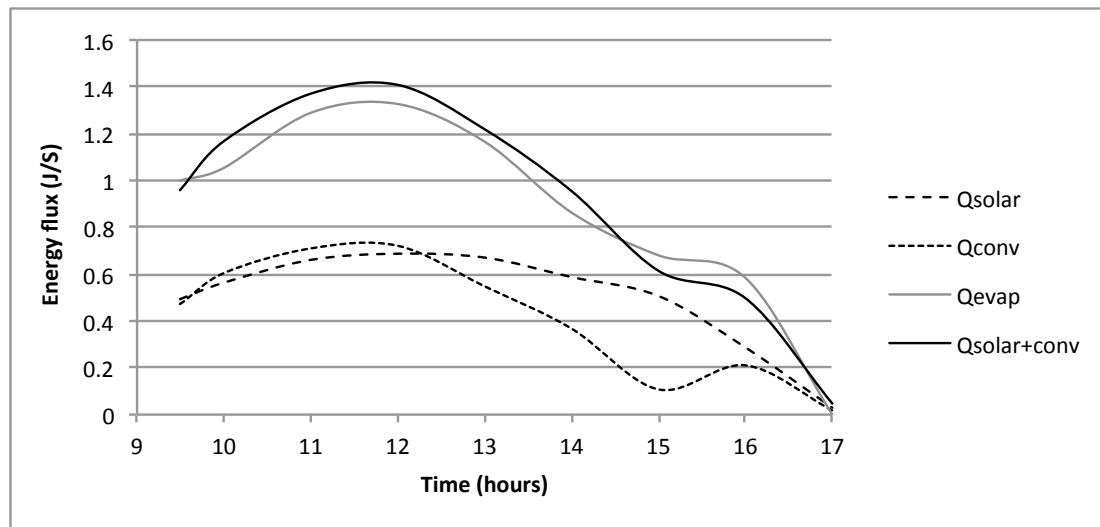


Figure 62 – Heat transfer rates via solar radiation, convection and evaporation on the solar dryer crop for Day 1 of Test 3.

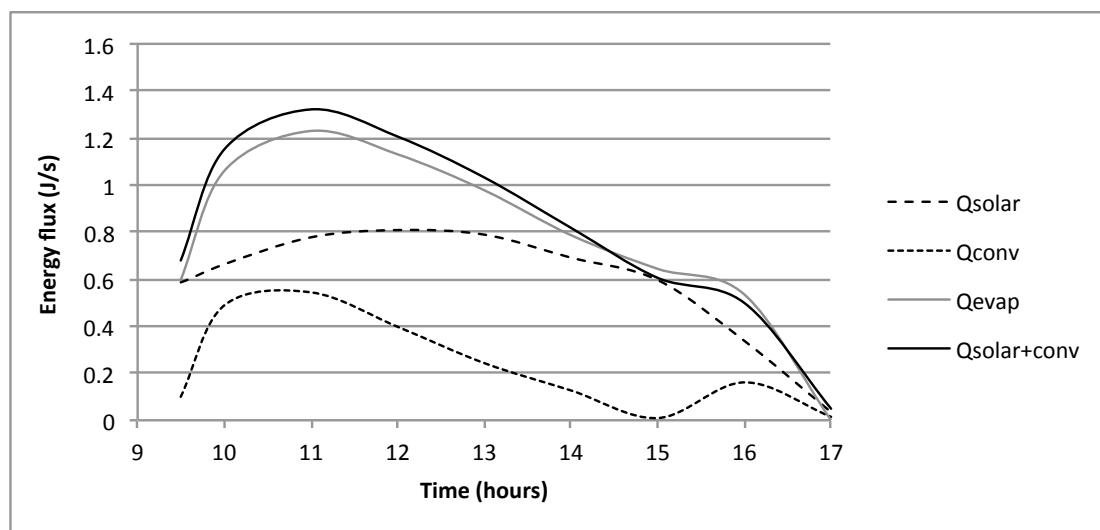


Figure 63 - Heat transfer rates via solar radiation, convection and evaporation on the sun drying crop for Day 1 of Test 3.

Figure 61 showed that the average drying rates in the dryer were faster than that of sun drying. To determine if this is consistent throughout the dryer, drying rates in different parts of the dryer will be compared.

Analysis of variance was used to determine if drying rates were significantly different across trays and between trays in the dryer. The results (assuming normal distribution with 95% confidence interval, $\alpha = 5\%$ or 0.05) are shown below:

Across trays:

$$F_{crit}(4,10) = 3.47$$

$$\text{Test 1: } F(4,10) = 0.21, \quad p = 0.93$$

$$\text{Test 2: } F(4,10) = 0.72, \quad p = 0.59$$

$$\text{Test 3: } F(4,10) = 0.34, \quad p = 0.85$$

Between trays:

$$F_{crit}(2,12) = 3.88$$

$$\text{Test 1: } F(2,12) = 4.36, \quad p = 0.04$$

$$\text{Test 2: } F(2,12) = 5.24, \quad p = 0.02$$

$$\text{Test 3: } F(2,12) = 13.53, \quad p = 0.0004$$

F is the ratio of two scaled sums of squares reflecting different sources of variability, essentially the ratio of explained variance (between groups) to unexplained variance (within groups). The p value is the level of significance. F_{crit} is the value that F must exceed for the results to be significant. From these, it can be assumed that there is no significant difference between drying rates across trays in the solar dryer ($F < F_{crit}, p > \alpha$), but there is a significant difference between trays ($F > F_{crit}, p < \alpha$). For this reason, the drying rates between trays will be compared in more detail.

Figure 64, Figure 65 and Figure 66 show the drying curves for each tray and for the sun drying samples (except for Test 1 when the sun drying samples were damaged) for each test. For all trays, the drying rates are equal or better than that of the sun drying rate. In the dryer in general, Tray 3 has the lowest drying rate. Drying rates vary between Tray 1 and Tray 2, with the drying rate on Tray 1 sometimes being higher or lower than on Tray 2.

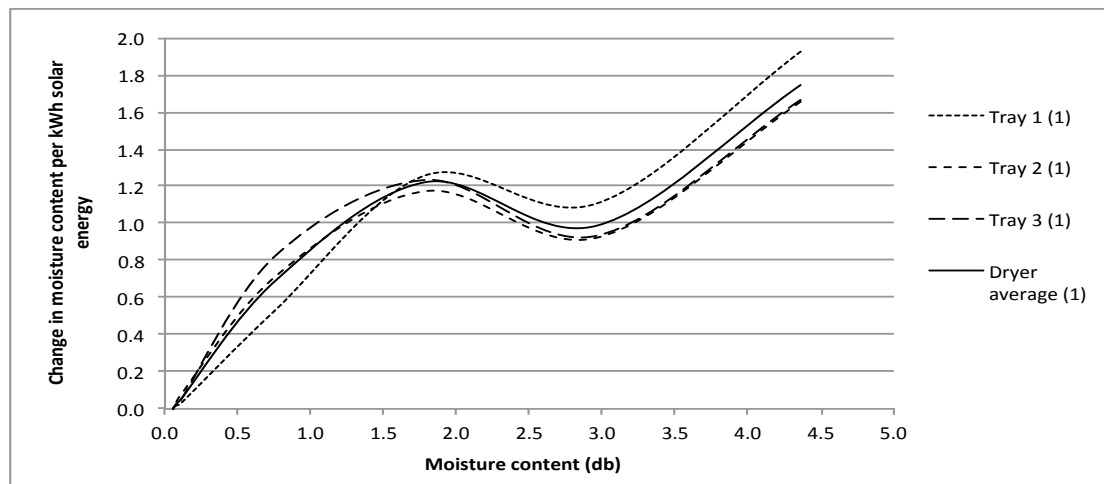


Figure 64 – Drying curves for each tray for Test 1.

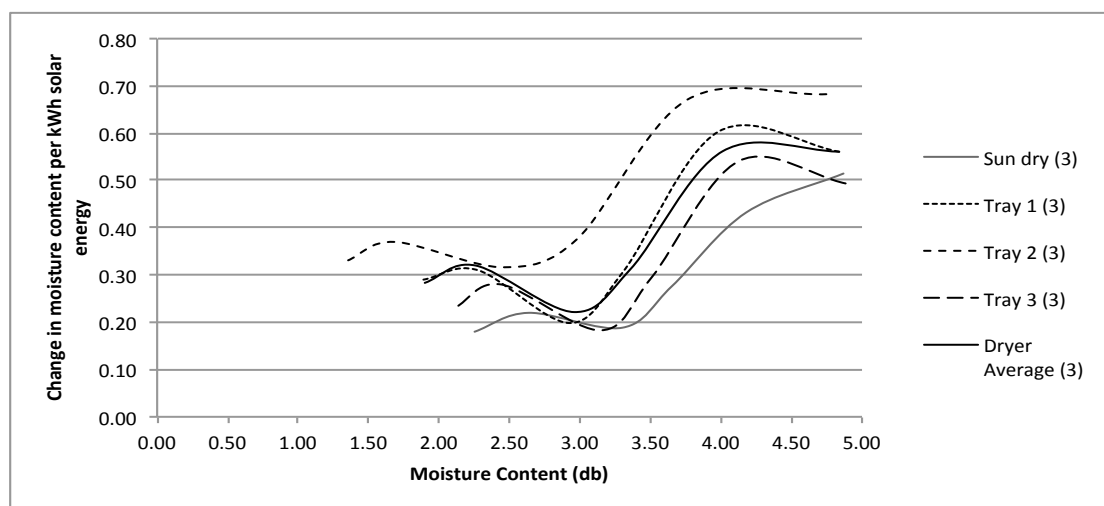


Figure 65 - Drying curves for each tray and sun dried sample for Test 3.

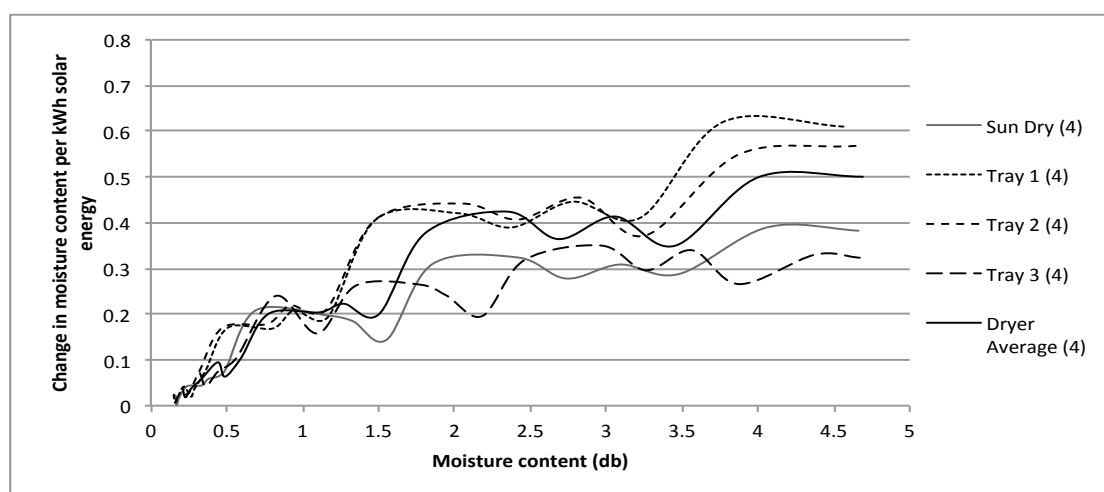


Figure 66 – Drying curves for each tray and sun dried sample for Test 4.

Table 34 shows the average difference between ambient and tray air temperatures for each tray for each test. These results mostly correlate with the drying rates for each tray shown in Figure 64 to Figure 66, but it is not evident why Tray 2 has a higher temperature difference and faster drying rate in than Tray 1 in Test 3. Without more data, it is not possible to know the reason for this result.

Table 34 – Average difference between ambient and dryer air temperatures above each tray for each test.

Test	Tray 1 Temperature (°C)	Tray 2 Temperature (°C)	Tray 3 Temperature (°C)
1	16.8	7.1	7.4
3	11.2	14.0	9.9
4	10.3	5.5	4.4

What can be derived from these results is that Tray 1 consistently has a higher drying rate than Tray 3. This indicates that that tray rotation of Tray 1 and Tray 3 during each drying test would be useful for more uniform drying in the solar dryer as a whole and potentially increase the average drying rate.

7.5.4 Crop production and nutritional improvement

The loading ratios, drying times and labour requirements presented in Section 7.5.2 will be used to predict the potential nutritional improvement from solar dryer produce over the harvest period. As stated in Chapter 5, the duration of the harvest period is 60 days and the available labour per family per day is one man hour, or 60 man hours over the entire period. It is assumed that the dried apples would be reconstituted prior to being eaten and that the fresh harvest weight translates directly to the reconstituted weight. As mentioned previously, the primary aim of adding apples to the winter diet is to address nutrient deficiencies not already addressed by the greenhouse produce, such as energy and zinc, and also to add diversity to the diet.

The best case scenario for drying time from the above results showed that 1.5 kg of apples could be dried in eight hours or one drying day (Test 1). If 1.5 kg were dried each day of the 60 day harvest season, it would potentially result in 90 kg of re-constituted apples for a family over winter. This would result in a daily portion of 200 grams for each family member (excluding the breast feeding baby).

This would, however, require 168 hours of labour overall, which is outside the constraint of 60 hours. If this constraint was applied, with assumption of a high drying rate like that achieved in Test 1, the dryer could be operated 21 times over the harvest period. Assuming that each load would produce 1.5 kg, this would result in a total 31.5 kg of apples for the winter period, or a portion of 6.67 grams per family member. This result is more realistic because a typical family in Humla farms on a small scale and currently only has access to around 20-30 kg of fresh produce for drying.

Figure 67 shows the cumulative nutritional improvement as a percentage of the RNI with greenhouse and solar dryer produce for a typical Humla family on a daily basis. It includes the potential nutritional improvement with the greenhouse alone, the improvement with the greenhouse and the best case scenario for solar dryer apple production, and the improvement for the scenario with the greenhouse and solar dryer produce where the labour constraint was enforced. These figures are based on the nutrient content stated in Table 17 in Section 5.3.1.

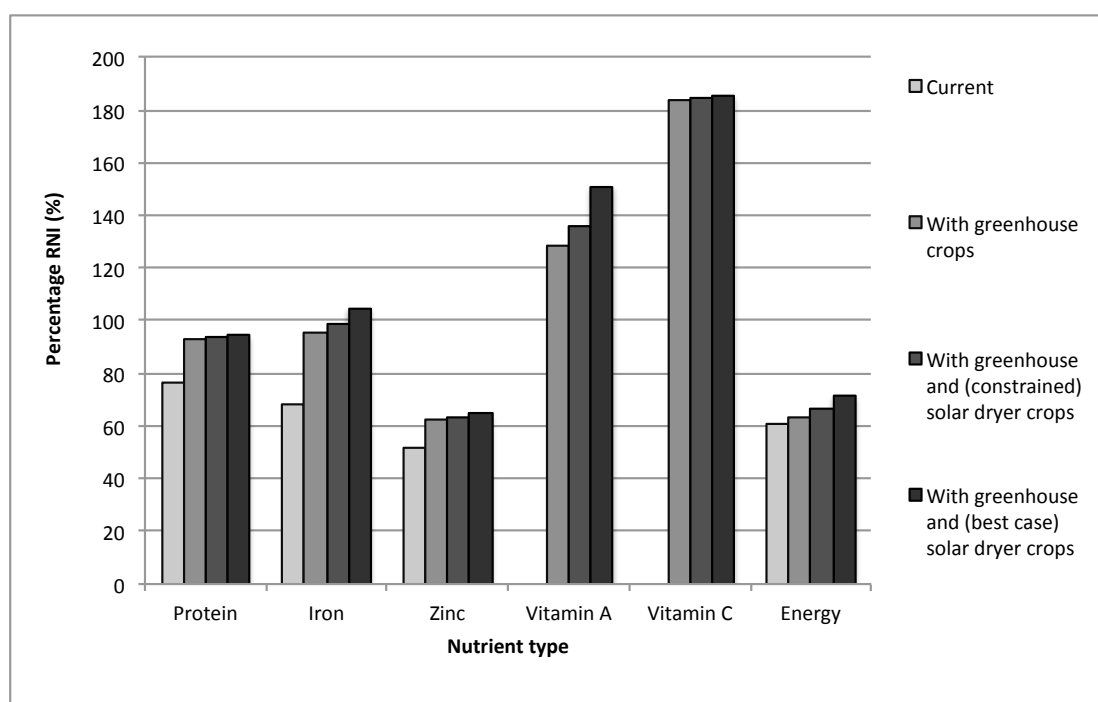


Figure 67 – Comparison of cumulative nutritional improvement with greenhouse and solar dryer produce for a typical Humla family.

There is some improvement in the nutrient levels with the addition of the solar dryer produce, however they are much smaller than that achieved with the greenhouse produce. The largest increases occur for vitamin A levels (20 percentage points), which would already be adequately addressed with the greenhouse produce. The best case scenario for apple production shows that an increase in energy levels of 10 percentage points could be achieved, but with the labour constraint enforced, this is reduced to only three percentage points. These results suggest that under current conditions relating to labour and available produce, potential produce from the solar dryer would not significantly improve nutrition for a typical Humla family compared to that of the greenhouse produce even with a high drying rate. Since nutritional improvement is the overall purpose for the implementation of these technologies, this suggests that it is potentially more beneficial to focus further research efforts in this project on the greenhouse.

7.6 Summary and Conclusion

In this chapter, the design selection, construction process and results for the experimentation process for the solar dryer were presented. These included the determination of initial moisture content, capacity and drying rates, uniformity of drying, airflow, shrinkage, thermal efficiency and a comparison between crop and air temperatures.

Based on considerations of material availability, cost and experience in other mountain areas, a simple Brace type solar dryer was considered to be most appropriate for use in Humla. A prototype was successfully constructed that satisfied appropriateness and cost criteria. The box-type design had a height of 0.5 m and a width and depth of approximately 0.6 m. The floor, walls and back door were all constructed from wooden planks with 2.5 cm thickness. The glazing was made from UV stabilized plastic, had an area of 0.45 m² and an angle of 30° to the horizontal. The input and outlet vents were located at the bottom front and top back, and had an area of 0.06 m² and 0.05 m² respectively. The overall tray area was 0.42 m², with one tray of 0.11 m² at the high level and two trays of 0.22 m² and 0.11 m² at the lower level.

When tested it was found that drying times varied between 1 – 5 days, depending on ambient conditions and thickness of samples, with thinner samples found to have a faster drying rate per volume of crop (1.5 kg/day compared to

0.9 kg/day). The average dryer air temperatures varied between 30-40°C, which is lower than the recommended 50-60°C for agricultural crops. Larger variations in drying rates between trays were apparent than across samples on each tray. This suggests that trays should be rotated to ensure more uniform drying throughout the dryer and potentially increase drying rates.

The results show that it was possible to dry the samples to a safe storage moisture content before spoiling, but that this could not be achieved consistently in Humla. A number of tests failed due to erratic weather conditions during the harvest period. In the testing performed in Humla and in Melbourne, it was found that the solar drying rate was better than the sun drying rate overall, but only marginally.

A possible solution to this problem would be to store the apples for a period of time in a cool store until conditions are better and more labour time is available and then attempt to dry them. The comparison of normalised drying rates based on ambient solar energy, showed that tests performed under different ambient conditions could be compared to determine the effect of other aspects influencing the drying rate. This suggests that the results of tests performed in less remote areas could be used to predict the outcomes in remote areas if the ambient conditions were known. With more data, a transferable method could potentially be developed, but is a subject for further research outside this project. The low nutritional contribution from apples (10 percentage points or less for protein, iron, zinc and energy, the nutrients not already addressed with the greenhouse produce) and the higher labour required, suggest that the solar dryer is not the most appropriate technology to improve food availability and nutrition in Humla under current conditions, even if performance improvements could be achieved through modeling and simulation. For this reason, it was decided to focus on improving the greenhouse performance via simulation, which will be the subject of Chapter 8.

7.7 References

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Chapter 8

Greenhouse Modelling and Cost Reduction

8 Greenhouse Modelling

In Chapter 6 it was established that a greenhouse could be successfully constructed and operated in Humla and could potentially produce enough vegetables to address nutritional criteria even though performance criteria was not satisfied. An appropriateness criterion was not entirely satisfied, however, since the cost of construction was high. Investigation of a theoretical “unskilled” construction scenario showed that costs could be reduced if farmers rather than skilled tradesmen built the greenhouses, but still the costs were comparatively higher than local people could afford.

The aim of this chapter is to investigate further scenarios that would reduce the construction cost of the greenhouse to make the design more appropriate. To reduce the time required to be spent by researchers in remote areas, this will be done via simulation. It also explores how accurately the greenhouse can be modelled with limited data and in non-ideal circumstances to determine if simulation can be used in place of a pilot program to refine the design for this particular area.

In Section 8.1, a description of the model is presented, outlining the major components of the model, parameters used and assumptions made. The model is then validated in Section 8.2 with experimental data collected over the winter season from January to March 2009, focussing primarily on air temperature and also on relative humidity. In Section 8.3, the validated model is used to explore further cost reduction strategies while maintaining current greenhouse conditions, with a particular focus on air temperature. These are followed by some concluding remarks in Section 8.4. The results from this section will be discussed further in the context of the entire research project in Chapter 9.

8.1 Model Description

This section describes the methods used to model the greenhouse and justifies the parameters used and assumptions made. According to Fuller et al. (2009) numerous dynamic thermal models have been developed to investigate the thermal performance of greenhouses. Most of these are in industrialised countries and have been developed for traditional greenhouse structures. The proposed

Humla greenhouse design has more similarities with a typical building rather than a traditional greenhouse due to the masonry walls used to passively regulate temperature with thermal mass. Cropping levels will also be low compared to a modern greenhouse practice, requiring less complex models for humidity and CO₂ levels. For the above reasons, a more traditional building model, Type 56 in the solar simulation program TRNSYS, was used to investigate the thermal performance of the greenhouse rather than a specialist greenhouse model.

The TRNSYS Type 56 building component allows the user to define a building of any size or shape with user-supplied parameters to define material properties and dimensions. Schedules are used to determine inputs at specified times. A radiation processor within TRNYS uses horizontal radiation data to calculate hourly values of solar radiation on all of the building's surfaces. The main user supplied parameters in the TRNSYS Type 56 model include material properties, dimensions, humidity gains from plants, infiltration and ventilation.

8.1.1 Material properties and dimensions

The properties of greenhouse materials were mainly sourced from literature and are listed in Table 35. Material properties for clay were used for the rendering on the stone walls and material properties for loose straw were used for the straw insulation in between the double walls. The layering of materials in the model structures is outlined in Table 36.

Table 35 – Material properties used in simulation model.

Material	Density (kg/m ³)	Specific Heat Capacity (kJ/kgK)	Conductivity (W/mK)	Reference
Wood (pine)	400	1.30	0.10	(Simpson & TenWolde 1999)
Earth	1300	0.88	1.20	(Lipiec, Usowicz & Ferrero 2007)
Stone (dry stone)	1716*	0.82	1.35	(Cardinale et al. 2011), (*estimated)
Clay	1500	1.80	1.50	TRNSYS library
Straw (loose)	60	0.60	0.07	(Goodhew & Griffiths 2005)
Metal sheet	7210	0.14	48.1	TRNSYS library
Plants (spinach)	899	2.1	0.35	(Delgado et al. 1997; Kreith, Manglik & Bohn 2010)

Table 36 – Material layers in major model structures.

Structure	Layers	Layer Thickness (m)
Stone (insulated)	Clay / Stone / Straw/ Stone / Clay	0.025 / 0.30 / 0.10 / 0.30 / 0.025
Stone (uninsulated)	Clay / Stone / Clay	0.025 / 0.70 / 0.025
Stone (uninsulated)	Stone	0.025 / 0.30 / 0.025
Roof (WSE*)	Wood / Straw/ Earth / Plastic / Earth	0.05 / 0.025 / 0.025 / 0.001 / 0.025
Wood (insulated)	Wood / Straw / Metal sheet	0.025 / 0.025 / 0.001
Wood (uninsulated)	Wood	0.025
Floor	Earth	0.10

* WSE – Wood-Straw-Earth construction

The Window 5 program was used to create glazing models for the greenhouse. It is a publicly available computer program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients and visible transmittances) and can be used to create new window types for the TRNSYS window library. Two window models were created: double glazed and single glazed, both with wooden frames. Most of the greenhouse glazed area is double glazed, except for the bottom corner sections at the front of the greenhouse where the additional vents were installed (Figure 68). Although UV stabilized polyethylene was used on the experimental greenhouse, the glazing was modelled with normal PET film and a 100 mm air gap. Since the greenhouse had been in operation for a year prior to the experimental data being collected, this was done to account for degradation of the plastic over that time. The material properties for PET film are shown in Table 37 and the layers and thermal properties shown in Table 38. The value for IR transmittance was initially zero according to the material properties in the Window 5 library but was changed to 0.57 to reflect values found in literature.

Table 37 – Properties of PET film.

Material	Thickness (mm)	Solar transmittance*	Solar absorbance*	IR transmittance	IR emittance
PET film	0.1	0.862	0.033	0.57 ¹	0.35 ¹

* At 0 deg incidence angle, ¹ (Fuller, Meyer & Sale 1987)

Table 38 – Thermal properties of glazing models (calculated in Type 56).

Glazing	Frame	Frame area (%)	Layers	Layer thickness (mm)	Conductance (U-value, W/m ² K)	Solar heat gain factor (g-value)
Single	Wood	10	PET film	0.1	4.8	0.870
Double	Wood	10	PET film/Air/PET film	0.1/100/0.1	2.1	0.772

The dimensions and orientation for the major model components (walls, roof, doors, vents, glazing and floor) are shown in Table 38. Figure 68 shows these aspects represented in a diagram.

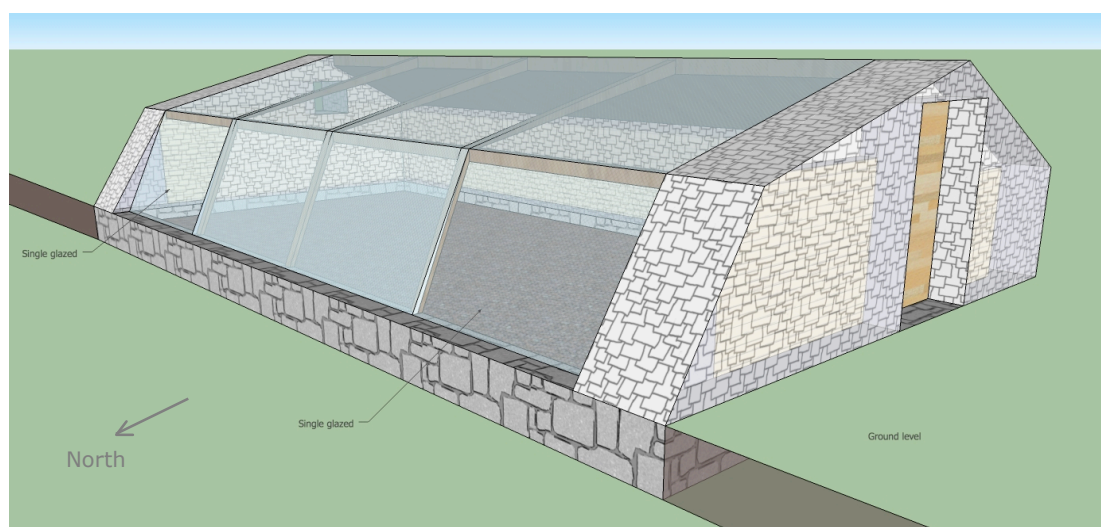
**Figure 68 – Scale diagram of greenhouse showing composition, distribution and orientation of model components.**

Table 39 – Composition, dimensions and orientation of major model components.

Component	Composition	Total Thickness (m)	Orientation (deg)		Area (m ²)
			Direction facing	Angle (from horizontal)	
North wall	Stone (insulated)	0.75	0	90	9.50
	Stone (uninsulated)	0.75	0	90	1.25
	Stone (uninsulated)	0.35	0	90	0.25
East wall	Stone (insulated)	0.75	90	90	2.96
	Stone (uninsulated)	0.75	90	90	2.07
Door	Wood (insulated)	0.05	90	90	1.50
West wall	Stone (insulated)	0.75	270	90	4.36
	Stone (uninsulated)	0.75	270	90	2.24
Window	Wood (uninsulated)	0.25	270	90	0.24
Roof	Roof (WSE)	0.13	0	30	8.30
Roof vents	Wood (insulated)	0.05	0	30	1.53
Earth floor	Earth	0.10	n/a	0	34.4
Plant canopy	Plants (spinach)	0.01	n/a	0	50.0*
Glazing (56° slope)	Single	0.001	180	56	6.30
	Double	0.1	180	56	6.30
Glazing (16° slope)	Double	0.1	180	16	21.6

*includes both sides of internal wall, necessary for TRNSYS calculations.

Assumptions were made regarding the material properties of the dry stone walls. Initially the material properties for granite were used, but preliminary validation results showed discrepancies between the experimental and simulation results (see Section 8.2, Figure 74). This was thought to have been due to the dry wall construction method and clay rendering. Dry wall construction, involving the simple overlap of stone layers without mortar, creates numerous voids of air inside the masonry which hinder thermal flow passage (Cardinale et al. 2011). Specifically this affects density and conductivity. Specific heat capacity is assumed to be unaffected by voids because the heat capacity of air voids per kilogram is negligible compared to the heat capacity of stone (this is based on the assumption that the voids don't link up, which was based on observation of the stone packing density). Overall volumetric heat capacity will be reduced, but that would be accounted for by the reduction in density. Clay rendering has a lower conductivity than granite (Table 40), inhibiting the flow of heat through the surface of the wall compared to that of plain granite. This reduces heat losses through the wall but also reduces the amount of heat that is stored.

It was not possible to measure the thermal properties of the dry stone walls in Humla, so it was necessary to estimate them according to information found in literature. Very little data exists on the thermal properties of dry stone walls, but it can be assumed that their thermal properties sit within a range between those of granite and materials such as Air-crete, which are intentionally produced with a high percentage of voids (70%) for insulation (Tarmac 2011) (see Table 40).

According to a study by Mundell & McCrombie (2009), dry stone walls can have between 20-40% of their volume as air pockets or voids. Based on the observations of construction in Humla, it is assumed that the walls consist of 40% voids. The density of the local granite was estimated by measuring the weight and volume (by submerging them in water) of rock samples, and found to be approximately 2640 kg/m³. The density value used in the wall model was then reduced by 40% to account for the method of dry wall construction (Table 40).

Cardinale et al. (2011) conducted an investigation into the conductivity of dry stone wall buildings built with calcareous stone in Trulli di Alberobello in Italy. Although calcareous stone is not identical to granite, it was found to have similar thermal properties (Table 40). For walls that were 0.74 m thick, the thermal conductance was found to be 1.823 W/m² K, which corresponds to a conductivity of 1.349 W/m K. The thermal properties for the dry stone walls in Humla have been estimated based on the values discussed above and are shown in Table 40.

Table 40 – Comparison of material properties of wall components.

Material	Density (kg/m ³)	Specific Heat Capacity (kJ/kgK)	Conductivity (W/mK)	Reference
Granite	2640	0.82	3.00	(Cornwell 1977)
Clay	1500	1.80	1.50	TRNSYS library
Calcareous Stone	2680	0.76	2.65	(Cardinale et al. 2011)
Calcareous dry stone wall	-	-	1.35	(Cardinale et al. 2011)
Humla Dry stone wall	1716*	0.82	1.35	(Cardinale et al. 2011), (*estimated)
Air-crete (70% air pockets)	600	1.0	0.15	(Tarmac 2011)

* density verified with simple tests and then reduced by 40%.

8.1.2 Plants

Since various plants were planted in the greenhouse at the same time it was not possible to use a specific crop model to model the plants. The remote location and caretaking of the greenhouse by the local NGO also meant that the researcher had little control over planting schedules. This was not considered to be detrimental to the outcome of the research however, since the results from Chapter 6 had shifted the focus of the modelling to reducing cost and maintaining performance, rather than increasing crop production.

Instead, the plant canopy was modelled as an additional internal horizontal surface to account for radiative and convective heat transfer, with thermal properties shown in Table 35 and dimensions shown in Table 38. Thermal properties for spinach were used, since the greenhouse crop was predominantly green leafy vegetables. Due to the high infiltration rate, high CO₂ levels were not considered to be an issue and were not included in the model (pers. comm R Ford, 2010). Transpiration and respiration from the plants was modelled as an additional humidity gain in the greenhouse air, determined from experimental results. Although simple, this method also takes into account any potential increase in evaporation due to the lower pressure at high altitude. For greenhouse crops, the formula most currently used until now for transpiration rate prediction is based on a simple linear correlation with solar radiation (Morris, Neale & Postlethwaite 1957; Stanhill & Scholte-Albers 1974). A linear coefficient of 0.0003 and a constant of 0.16 were found to approximate the inside humidity gain well during January and the beginning of February, when ventilation was also taken into consideration. These coefficients were validated by comparing measured and simulated absolute humidity data (see Section 8.2, Figure 76). The root mean square (RMS) error, indicating how well the simulated data matches the measured data, was found to be 2.6 g/m³. The humidity gain equation used in the model is shown below:

$$\begin{aligned} \text{Humidity gain} &= 0.0003 \times \text{Solar Radiation on horizontal} + 0.16 \\ (kg/hr) & \quad (kJ/hr/m^2) \end{aligned} \quad \text{Eq. 14}$$

In the middle of February however, a step change occurred in greenhouse absolute humidity (see Section 8.2, Figure 86Figure 87). This was thought to be

caused by one or a combination of two events. The first was the fact that additional crops were planted in the greenhouse at this time. Prior to this, the greenhouse crop had been predominantly green leafy vegetables, but in mid-February squash and tomatoes were planted, and cauliflower heads were developing. It is thought that additional transpiration from these crops contributed to the increase in the absolute humidity of the greenhouse air. The second event was the increase in average greenhouse air temperature due to the increase of ambient temperature. An increase in temperature would allow the air to hold more moisture. It is possible that an increase in absolute humidity could also have been caused by a decrease in natural ventilation related to local wind conditions. Since wind data was not recorded, it was not possible to verify this with measured data. However, due to the consistency of the step change and since no corresponding increase in difference between measured and simulated air temperatures occurred, this was thought not to be the case. For this later period, the constant humidity gain value from Equation 13 (above) was increased from 0.16 to 0.2, which was validated by comparing measured and simulated absolute humidity data. The RMS value improved from 6.42 to 5.88. Although this is not as close a fit as for the results in January, Figure 88 shows that it is sufficient to produce good results for the relative humidity of the greenhouse air for this later period.

8.1.3 Infiltration and ventilation

Within Type 56, it is possible to specify the infiltration rate in the building as volume air changes per hour. According to Fuller et al (2009) an infiltration rate of 1.0 volume air change per hour is reasonable for a polyethylene-covered greenhouse and this value was used for the greenhouse model. Type 56 also has a ventilation function, however it is based on mechanised ventilation systems in buildings and not considered suitable for the naturally ventilated greenhouse. Instead, the natural ventilation in the greenhouse was modelled as an additional infiltration at the times when the vents were open. Some basic airflow measurements were taken with a hand-held anemometer in front of the front vents, door and roof vents in September 2009 (refer to Chapter 6), which gave ventilation rates of 30 air changes per hour. These did not correlate well with expected ventilation rates of 2-3 air changes per hour for a naturally ventilated greenhouse (Buffington et al. 2010) and did not produce simulated air absolute humidity and temperature values that were comparable to the measured data.

The ventilation rate was estimated at 1.0 volume air changes per hour between 9am and 4pm each day, in addition to the base infiltration rate of 1.0 volume changes per hour, giving a total ventilation rate of 2.0 volume changes per hour. This corresponds with expected ventilation rates for naturally ventilated greenhouses and was verified by comparing measured and simulated air absolute humidity and temperature values (see Section 8.2).

8.1.4 Incident solar radiation on inside surfaces

Since the greenhouse has substantially larger windows than a normal building, it was necessary to model the effect of the incident solar radiation on the inside surfaces such as the walls and floor. This is done using the *geosurf* parameter in Type 56. This parameter indicates the fraction of the total incoming solar beam radiation incident on any of the inside surfaces. It can be defined as a constant value, an external input or a schedule for each surface. The calculation of these factors depends on the incident angle of the solar radiation and the area and orientation of each illuminated surface.

Figure 69 to Figure 72 show the shading patterns on the interior surfaces of the greenhouse at four different times of day in late January. Due to the nearby mountains, beam radiation doesn't strike the greenhouse until 9.30am, when sun is shining predominantly on the front of the greenhouse and incoming radiation strikes the side walls at a very shallow angle, resulting in minimal heat transfer. The back wall is partially illuminated at this time of day (Figure 69). At 3.30pm, after which the sun is again blocked by nearby mountains, the opposite illumination of the greenhouse occurs (Figure 72). In the middle of the day, the back wall changes from being partially illuminated in January (Figure 70 and Figure 71) to completely shaded in March, when the solar elevation is sufficient so that the roof blocks solar beam radiation on the back wall.

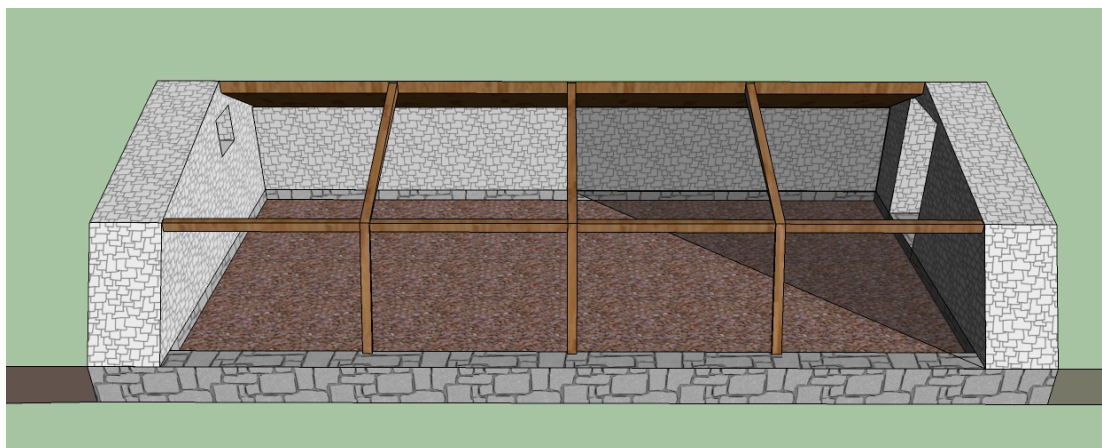


Figure 69 – Illumination for interior greenhouse surfaces by beam radiation at 9.30am on a typical day in January.

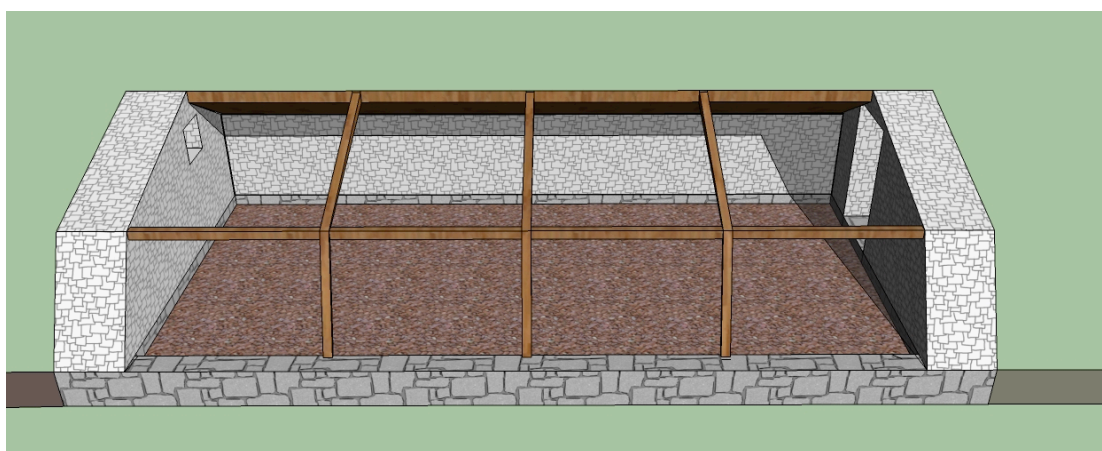


Figure 70 – Illumination for interior greenhouse surfaces by beam radiation at 12pm on a typical day in January.

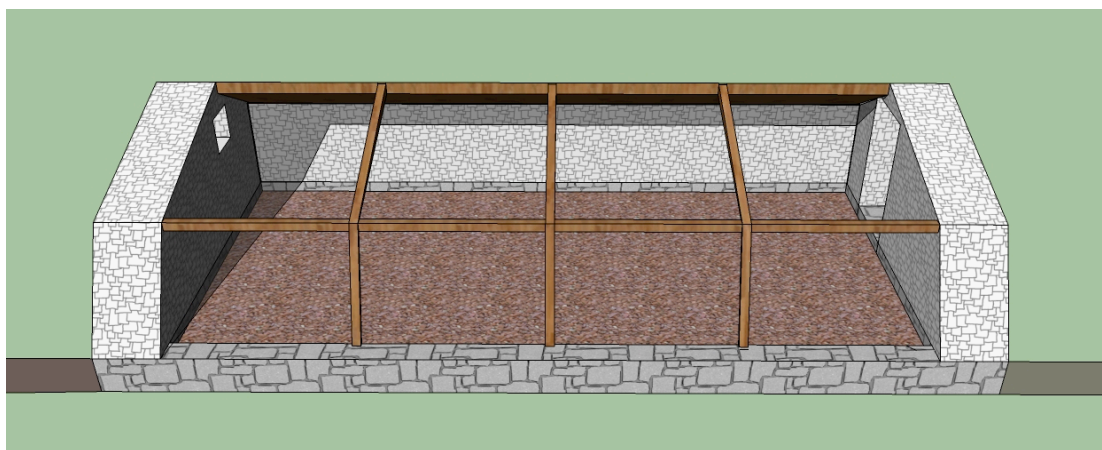


Figure 71 – Illumination for interior greenhouse surfaces by beam radiation at 1pm on a typical day in January.

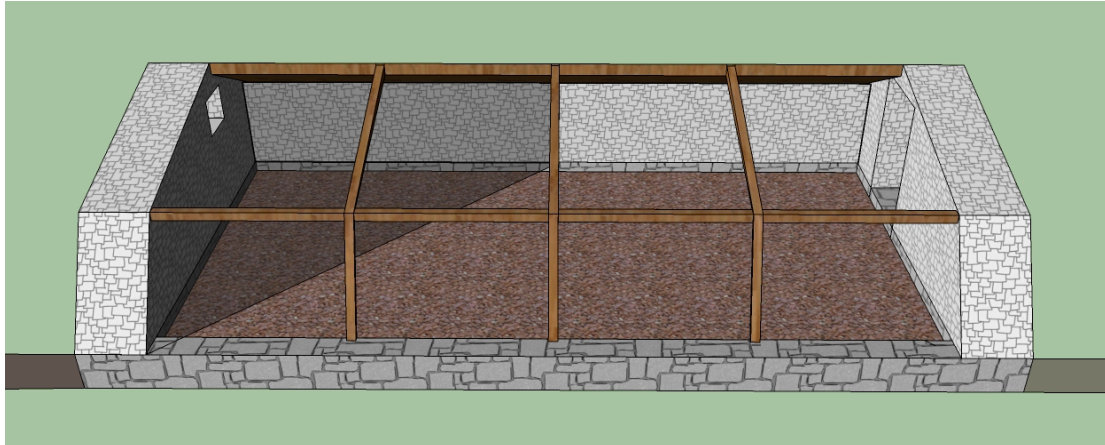


Figure 72 - Illumination for interior greenhouse surfaces by beam radiation at 3.30pm on a typical day in January.

Table 39 shows the percentage of effective incident beam solar radiation on each interior surface at different times of the day. These values were calculated based on the angle of incidence of the solar radiation and the proportion of the surface that was illuminated at that particular time. In the middle of the day, 86% of the incoming beam radiation falls on the floor of the greenhouse and 12% falls on the back wall. At the beginning and end of each day, 65% of the radiation falls on the floor, while 14% and 21% fall on the back wall and either the east or west side walls.

Table 41 - Average percentage of solar flux on each interior surface at different times of day over the winter period.

Time	Floor	Back wall	West Wall	East wall
9.30am	65	14	21	0
12.00pm	86	12	2	0
1.00pm	86	12	0	2
3.30pm	65	14	0	21

Figure 73 shows the product of the percentages shown in Table 39 and the actual incoming beam solar radiation at that time of day. At the time when the solar radiation flux is the highest, 86% of that radiation is falling on the floor of the greenhouse.

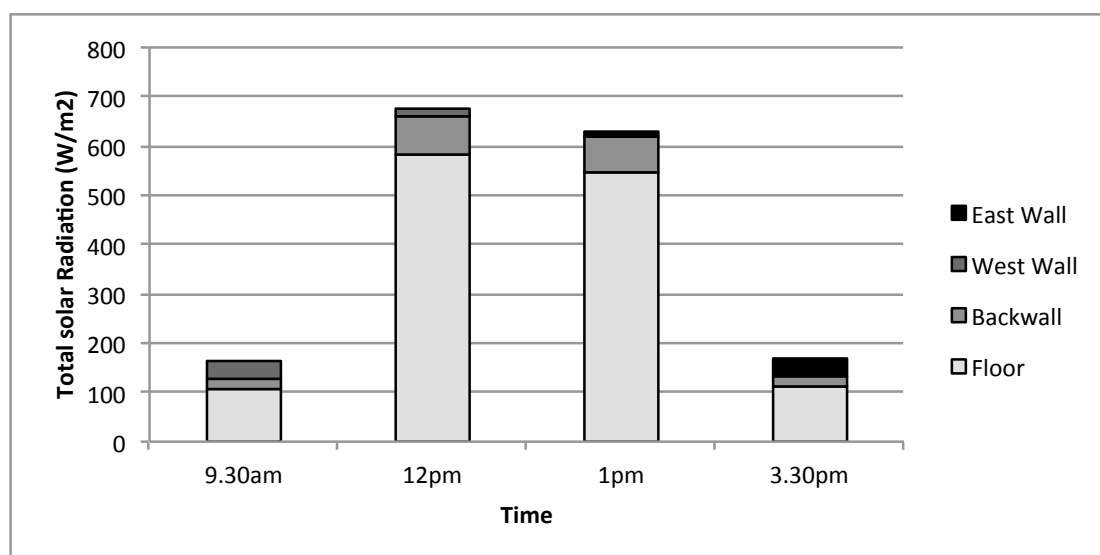


Figure 73 – Proportion of incident solar radiation in interior surfaces at different times of day in winter

For this reason it is assumed that the geosurf parameter is 0.85 for the floor of the greenhouse, 0.10 for the back wall and 0.05 for either of the vertical side walls depending on the time of day. Since the crops had been planted in November, the plant canopy was well established by January. It is therefore assumed that the plant canopy shades the earth floor. From values shown in Figure 47 and Table 23 in Chapter 6, the crop planting area is 75% of the total area inside the greenhouse, with the rest being taken up by walkways. This would suggest that the geosurf parameter should be split into 0.64 on the plant canopy and 0.21 on the greenhouse floor. It was observed however that shading from plant leaves extends partially across the walkways, so the geosurf parameter is instead split into 0.75 on the plant canopy and 0.10 on the earth floor. This was validated with a comparison of simulated and measured soil temperatures in Figure 80.

8.1.5 Radiation to sky

As mentioned in the previous section, a greenhouse differs from a normal building because a large percentage of its structure is glazed. This means that internal surfaces can effectively 'see' the sky through the glazing, and can therefore radiate heat to the surrounding environment, since the greenhouse is glazed with polyethylene that partially transmits thermal radiation. This is not the case in a normal building and radiation to the sky by internal surfaces is not calculated in the Type 56 component. For this reason, it is necessary to

incorporate an extra function into the TRNSYS model to approximate the radiation to sky.

According to Cooper and Fuller (1983) net radiation loss in watts from an opaque surface to the 'sky' (i.e. surrounding environment, assumed to be a black body at temperature T_{sky}) through double glazing can be approximated with the following equation:

$$Q_{rad-sky} = A \, vf \left[\begin{aligned} &\varepsilon_0 \sigma T_0^4 \left[1 - \alpha_0 (\rho_2 + \tau_2^2 \rho_1) \right] \\ &- \alpha_0 \left[\begin{aligned} &(1 + \rho_0 \rho_2 + \rho_1 \rho_2 + \rho_0 \rho_1 \tau_2^2) (\tau_1 \tau_2 \sigma T_{sky}^4 + \tau_2 \varepsilon_1 \sigma T_1^4) \\ &+ \varepsilon_2 \sigma T_2^4 (1 + \rho_0 \rho_2 + \rho_0 \tau_2^2 \rho_1) \end{aligned} \right] \end{aligned} \right] \quad \text{Eq. 15}$$

where the subscripts 1, 2, 0 and 'sky' refer to the outer glazing layer, inner glazing layer, opaque surface (i.e. wall or floor) and the sky. T refers to the temperature of each surface in Kelvin, the symbols ρ , τ , α and ε represent the reflectance, transmittance, absorbance and emittance of each surface to thermal radiation and σ is the Stephan Boltzmann constant. A refers to the area of surface and vf is the view factor relating to the orientation of the surface to the sky (horizontal = 1, vertical = 0.5). The values for these parameters are shown below in Table 42 (note: $\alpha + \rho + \tau = 1$, $\alpha = \varepsilon$). The area values are listed in Table 38. The view factor for the horizontal floor has been reduced due to shading by the plant canopy. Radiation exchange between the plant canopy and floor has already been accounted for in the TRNSYS model. The view factor for the horizontal plant canopy has also been reduced to 0.6 from a potential 1.0, since it does not have a complete hemispherical view of the sky due to the greenhouse walls.

Table 42 – Parameters used in radiation to sky calculation.

Surface	ρ	τ	α	ε	View factor to sky
Walls (granite)	0.55	0	0.45	0.45 ³	0.5
Floor (soil)	0.62	0	0.38	0.38 ³	0.4
Plant canopy	0.03	0	0.97	0.97 ¹	0.6
Inner glazing layer	0.08	0.57 ¹	-	0.35 ¹	-
Outer glazing layer	0.08	0.57 ¹	-	0.35 ¹	-

¹ (Fuller, Meyer & Sale 1987), ² Window 5 glazing library, ³ (Omega 1998)

The temperature of the walls, soil, plant canopy and glazing layers are calculated in Type 56 each time-step. A “delay” component is used to store these values to be used as inputs into the radiation to sky function at the beginning of the next time-step. The heat loss has been modelled as a negative wall gain for each of the interior walls. Some discrepancy may occur with the calculation for the walls since the wall gain will reduce the temperature of the entire wall, not just the interior layer. In reality, this probably would not occur due to straw insulation between stone layers.

8.2 Model Validation

The model was validated by comparing simulated and experimental data over January, February and March 2009, focusing on temperature and humidity of the greenhouse air. As discussed in Chapter 6, temperature is the most important parameter in greenhouse controls since it has a significant role in plant growth and development (Garzoli 1988). It is also important to keep relative humidity below 90% for disease control (Vaisala 2011). Data from one week in January is used below to show the process used to improve the model. It should be noted that the simulation was run for the entire month, starting from the same initial conditions. These results are a snapshot used to show how the model was improved and validated.

Experimental air temperature and humidity measurements were taken in the middle of the greenhouse to correspond with the method with which the zone temperature and humidity are calculated in the TRNSYS Type 56 building model. It is a non-geometrical balance model with one air node per zone, representing the thermal capacity of the zone air volume and capacities, which are closely connected with the air node (plants, for example).

Figure 74 and Figure 75 show the results for the greenhouse air temperature and relative humidity respectively, for the initial configuration of the model. This included the assumption of granite walls, no consideration of incident solar radiation on inside surfaces and no radiation to the sky from inside surfaces.

There is a good agreement between daytime conditions, but more discrepancy overnight. The RMS value overall is 3.8°C. The largest difference in temperature

occurs on January 16-17 overnight. It was mentioned previously that on this night the vents were left open on the night of 16 January, which was not accounted for in the regular ventilation schedule in the model. As mentioned in the previous section, temperature results show that the model does not account for additional heat gains or losses in the middle of the day or night respectively.

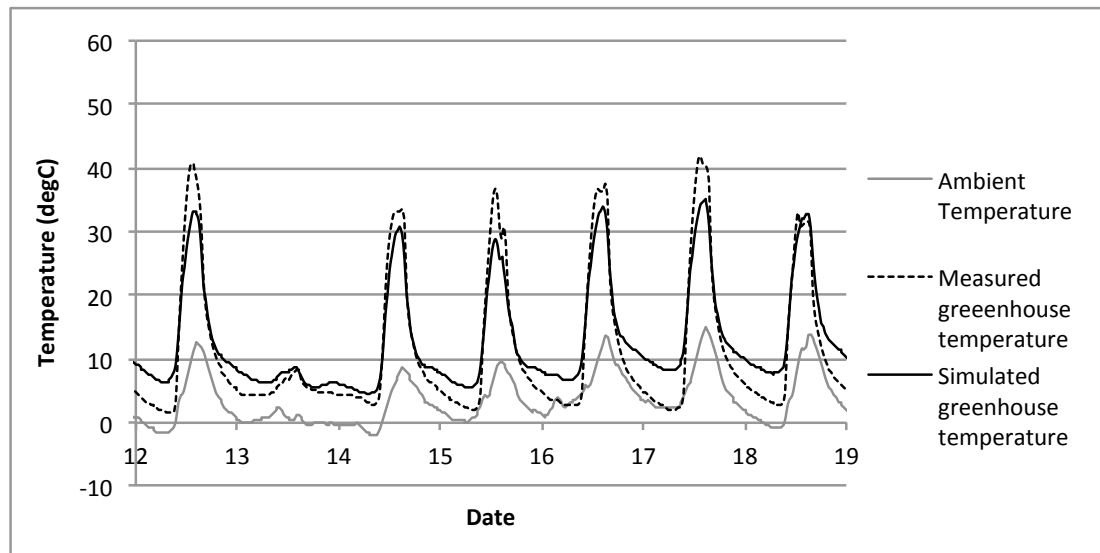


Figure 74 – Temperature comparison from initial configuration of model for January.

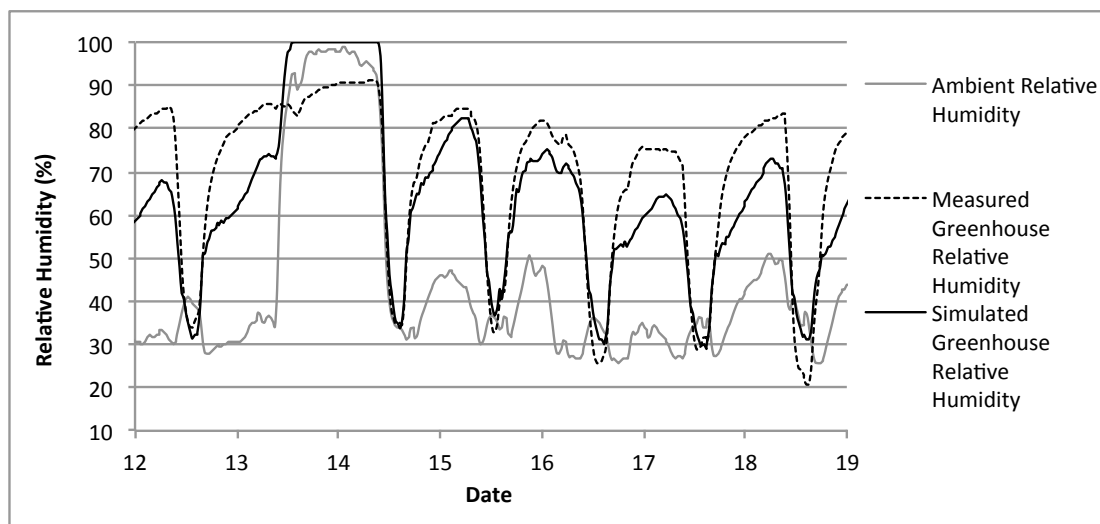


Figure 75 – Relative humidity comparison from initial configuration of model for January.

Relative humidity results also show discrepancies overnight and in the middle of the day in some instances, which could be caused by either differences in air

humidity levels or differences in air temperature, since relative humidity is a function of both. Overall the RMS error is 11.1%. Since the measured and simulated absolute air humidity levels correlate well at night (Figure 76), it is thought that the difference in relative humidity can be attributed to temperature differences overnight, suggesting that the assumptions related to the constant rate of humidity gain and infiltration overnight are valid for this period.

Discrepancies during the day could be caused by variable wind conditions, which will affect the natural ventilation. Since local wind data was not recorded over the experimental period, this could not be validated. The discrepancy however is small, no more than 5 g/m³ of greenhouse air. The simple ventilation and humidity models do produce similar average absolute humidity results of 7.77 and 7.08 g/m³ for the measured and simulated data respectively.

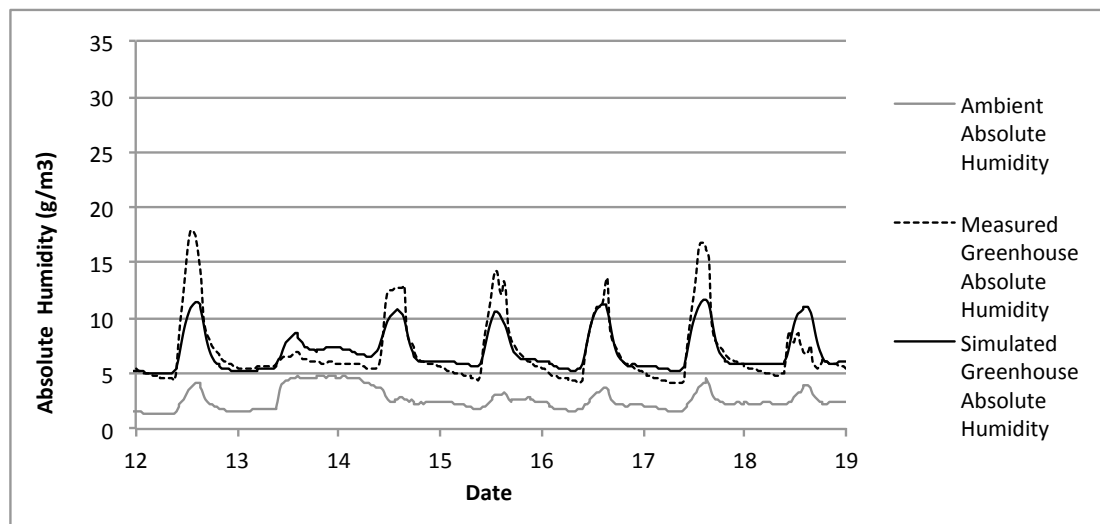


Figure 76 – Absolute humidity comparison from initial configuration of model for January.

Figure 77, Figure 78 and Figure 79 show the comparison of measured and simulated greenhouse air temperatures with the successive incorporation of additional functions. Each figure shows a gradual decrease in the amount that the simulated temperatures differ from the measured temperatures. Figure 77 shows that the addition of dry stone wall properties increases the maximum simulated temperatures during the day. Figure 78 shows that including the effect of incident solar radiation on interior surfaces increases daytime maximums of the simulated data further. For both these cases, however, the RMS values do not change from 3.8°C, indicating that the overnight simulated temperatures increased also.

Figure 79 shows that the inclusion of thermal radiation to the sky from interior surfaces reduces simulated night temperatures, bringing them closer to the measured data. In terms of the RMS error, the combination of these aspects reduces it to 2.6°C.

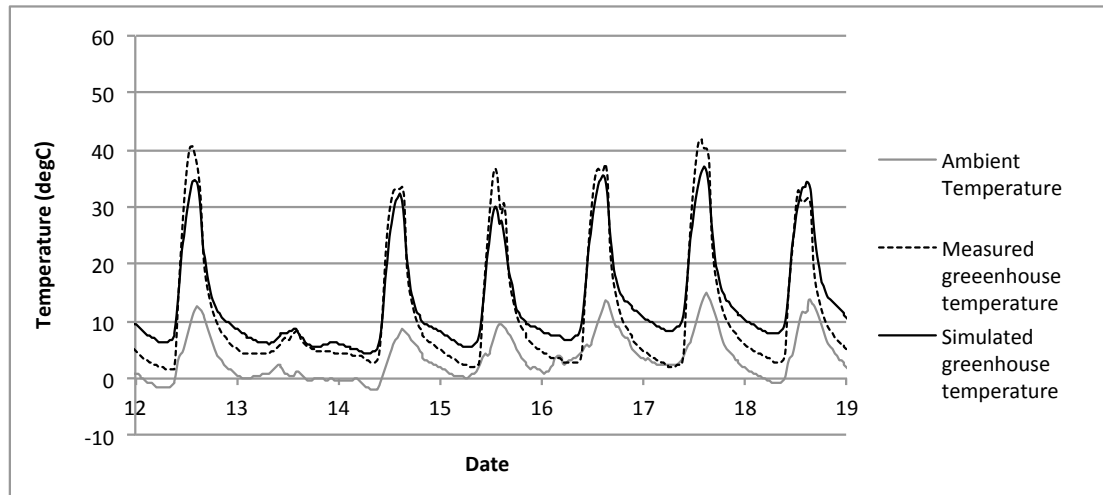


Figure 77 – Temperature comparison with dry stone wall properties for January.

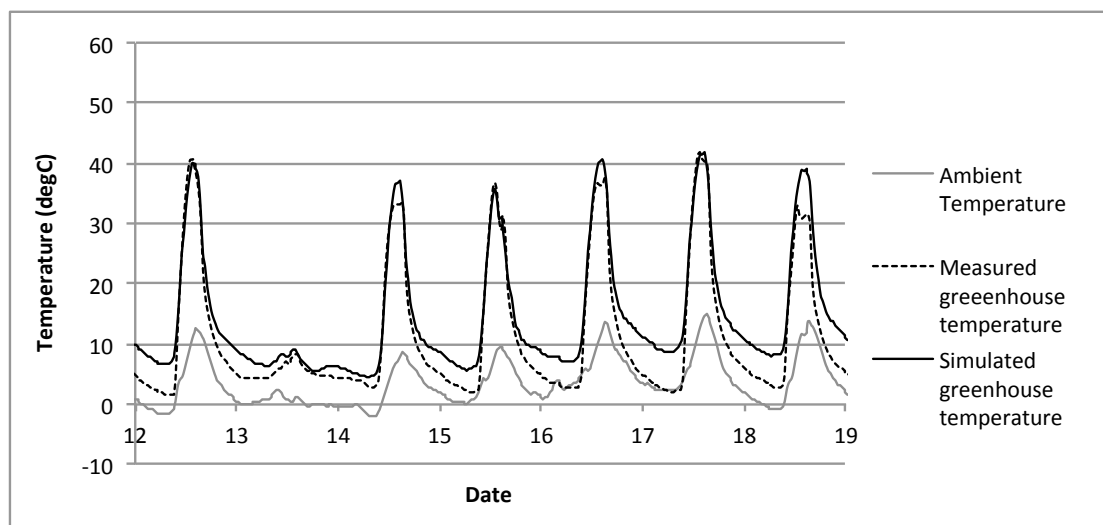


Figure 78 – Comparison of measured and simulated temperatures including dry stone wall properties and the effects of incident solar radiation on interior surfaces.

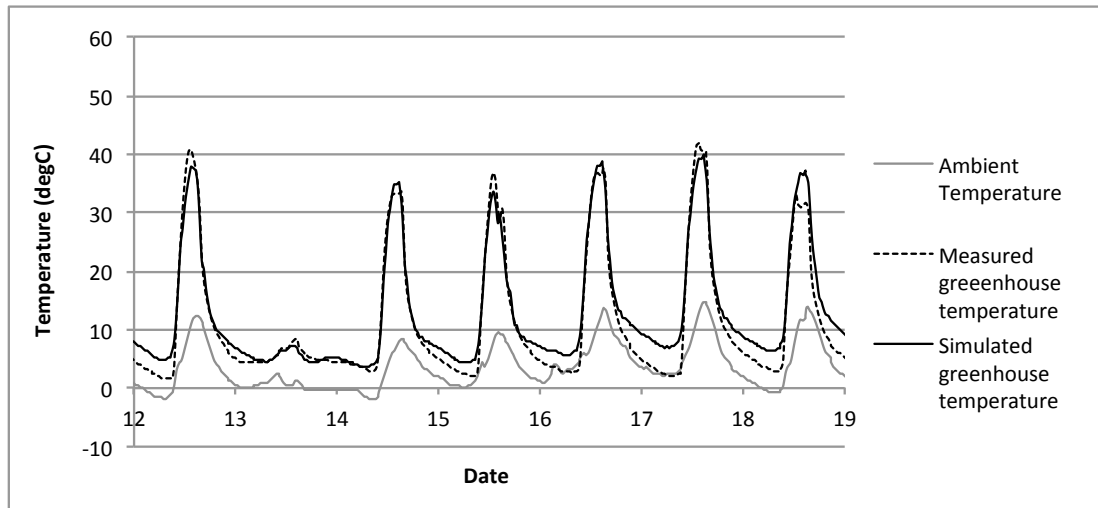


Figure 79 – Comparison of measured and simulated greenhouse temperatures including dry stone wall properties, effects of incident solar radiation and thermal radiation to the sky.

Figure 80 shows the comparison of measured and simulated soil temperatures, for the purposes of validating the effects of incident solar radiation and thermal radiation to the sky. Unfortunately, soil data for the 12 – 19 January was not recorded properly, so data from a prior week has been shown. There is a slight phase difference but otherwise a good correlation exists between the measured and simulated data, indicating that assumptions regarding heat gains and losses from the soil surface are valid.

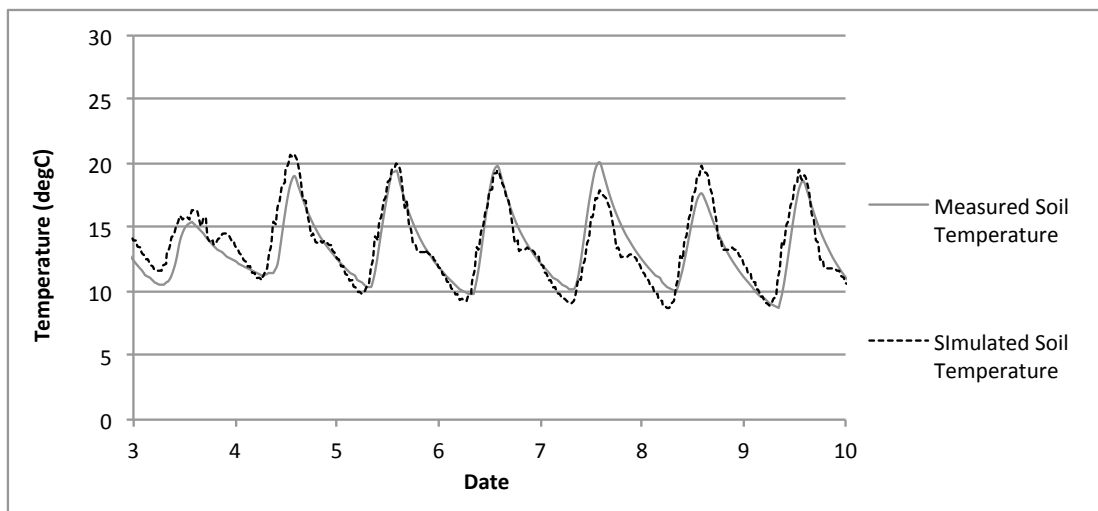


Figure 80 – Comparison of measured and simulated soil temperatures including incident solar radiation and thermal radiation to the sky.

Figure 81 shows the comparison of measured and simulated relative humidity. A good correlation has been achieved just by improving temperature results with no alteration to the humidity or ventilation functions. The RMS error was subsequently reduced to 8.5%.

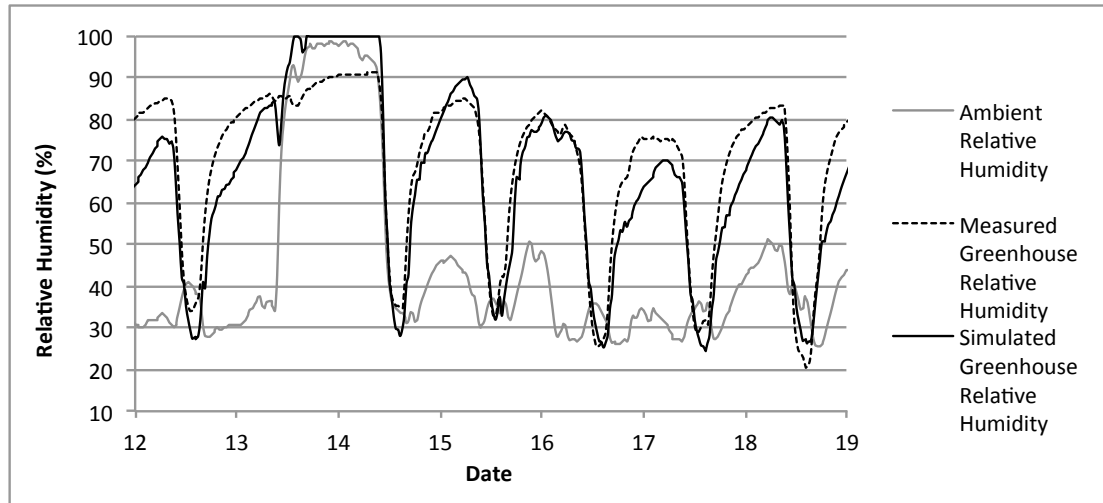


Figure 81 –Comparison of measured and simulated greenhouse relative humidity in January.

Figure 82 and Figure 83 show the comparison of measured and simulated temperatures for periods in February and March. It can be seen that even with increasing average ambient temperature, the simulated data still approximates the measured data well. The fact that the difference between maximum temperatures increases over time, and the difference between minimum temperatures decreases, indicates that over a longer period a possible systematic drift might occur. For this short winter period however, the drift is minimal, so the model is still considered to be valid for the purposes of this research.

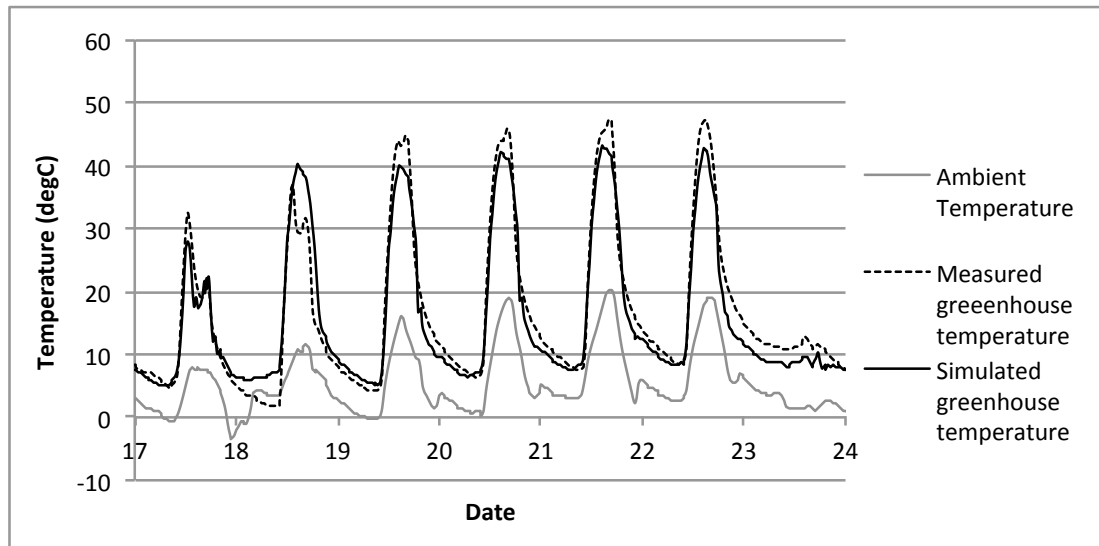


Figure 82 – Comparison of measured and simulated temperature results for February.

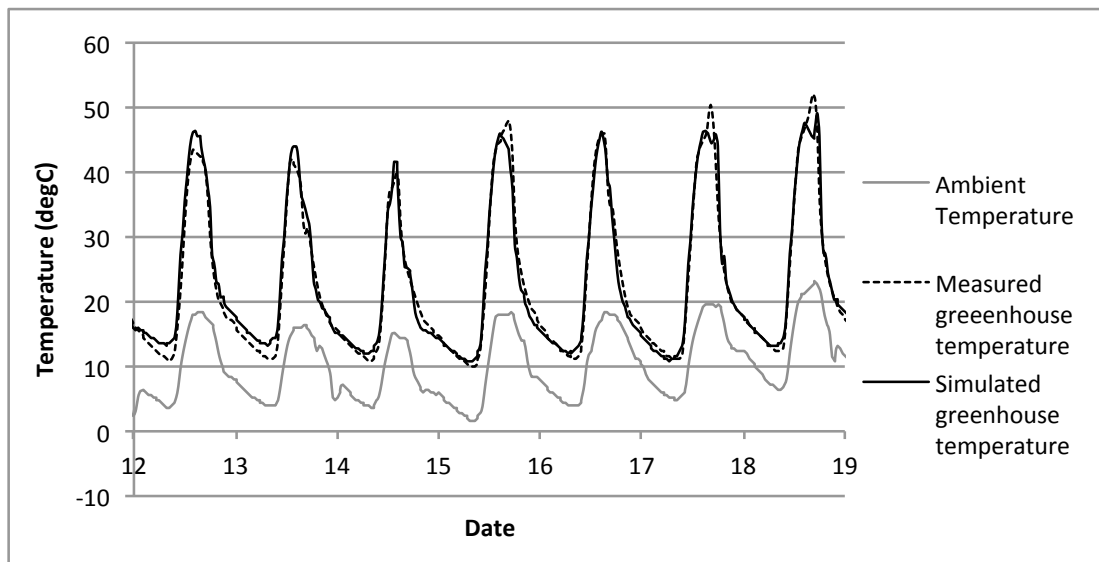


Figure 83 – Comparison of measured and simulated temperature results for March.

Although there was a good correlation between temperature data, the relative humidity results showed more discrepancies. Figure 84 and Figure 85 show the comparison of measured and simulated relative humidity in February and March. In the period from the middle of February to the middle of March there appears to be a step change in relative humidity measurements.

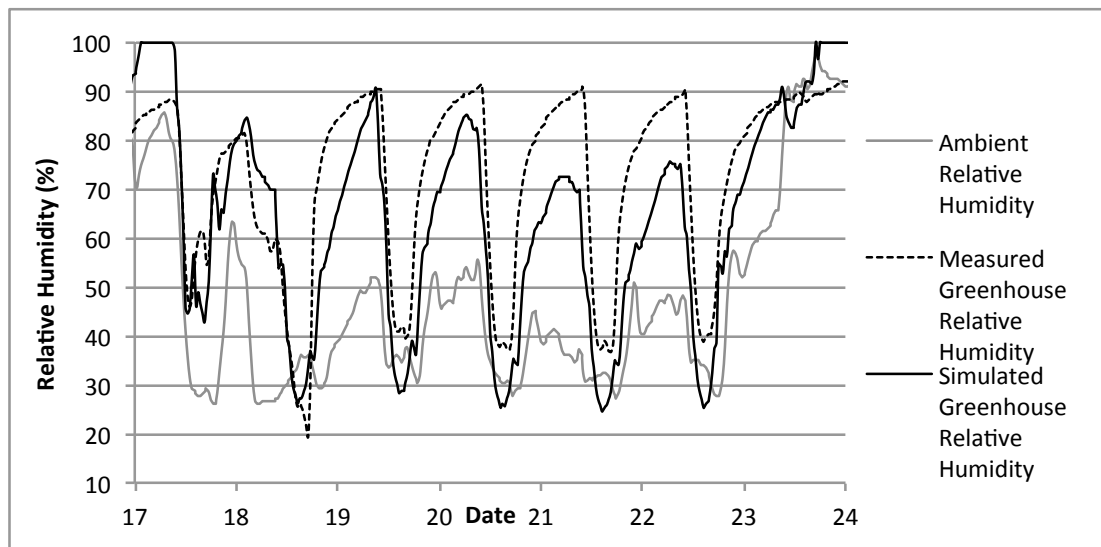


Figure 84 – Comparison of measured and simulated relative humidity for February.

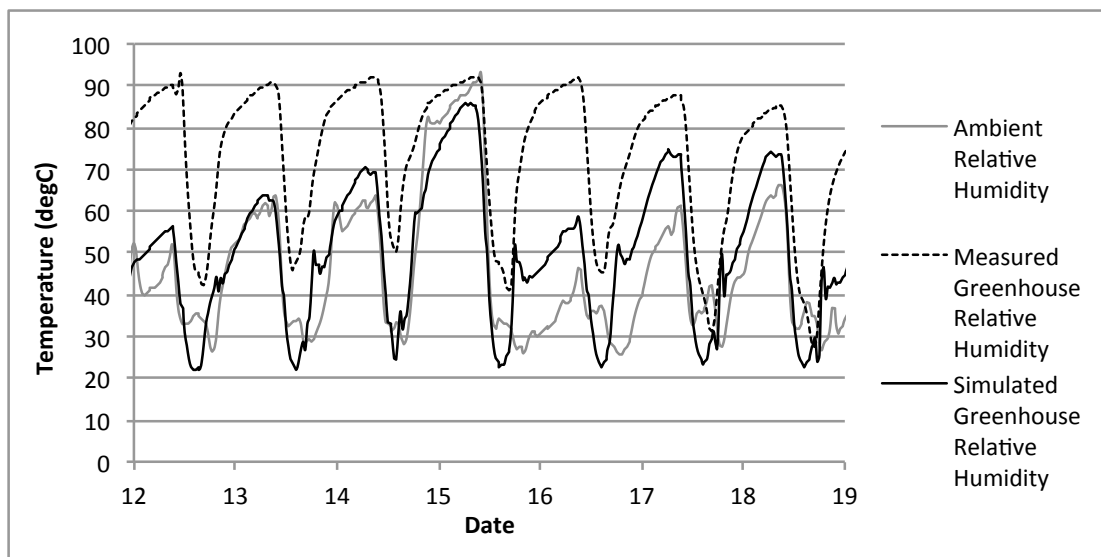


Figure 85 – Comparison of measured and simulated relative humidity for March.

The change is more apparent when comparing absolute humidity data (Figure 86 and Figure 87), indicating that the discrepancy is caused by increased humidity levels rather than temperature differences. As mentioned previously, according to the planting schedule, additional plants were planted amongst those already growing just prior to this period, increasing the density of crops in the greenhouse and changing the distribution from mainly leafy green crops to squash and tomato. This was combined with an increase in ambient temperature and a subsequent increase in greenhouse temperatures overall. Since the new

plants were planted amongst those already there, it is assumed that this did not change the canopy cover significantly.

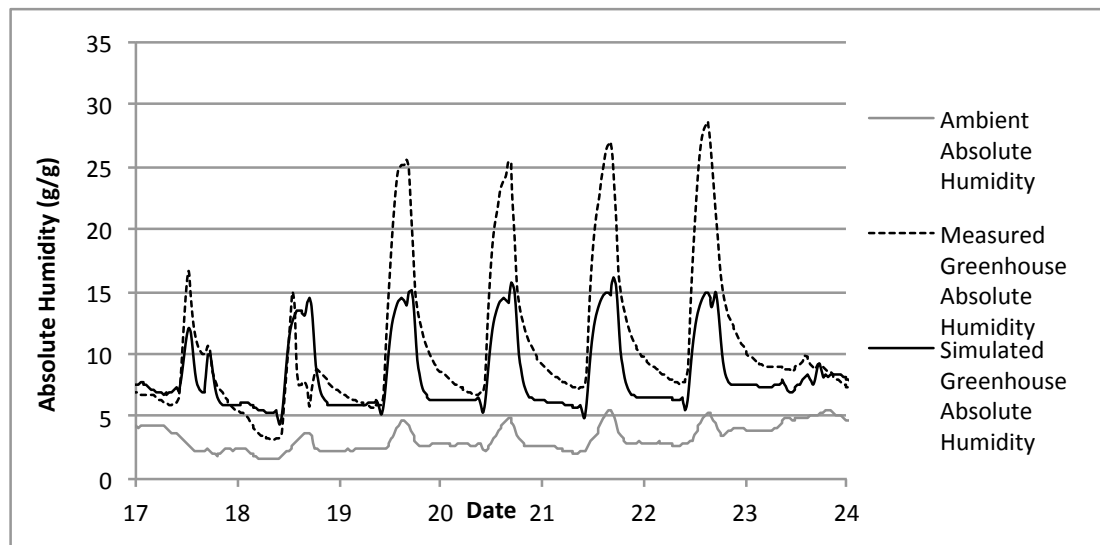


Figure 86 – Comparison of measured and simulated absolute humidity for February.

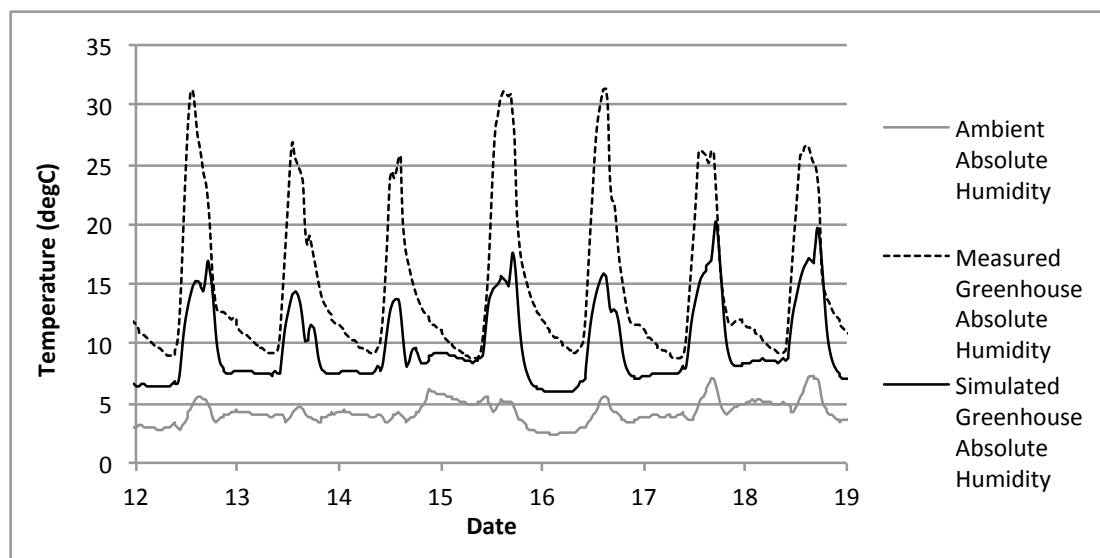


Figure 87 – Comparison of measured and simulated absolute humidity for March.

The constant humidity gain parameter in the model was increased from 0.15 to 0.2 for this later period, to determine if a simple humidity model would still be sufficient to predict greenhouse air conditions. The results for March are shown in Figure 88. These results show a better correlation between measured and simulated results, however discrepancies are still apparent. It is possible that

these discrepancies could be caused by an instrument fault. Humidity sensors, unlike temperature sensors, must be in direct contact with the environment, and are known to be subject to contamination and subsequent drift in measured values (Schellenberg 2002). For this reason they must be re-calibrated regularly. Due to the remote location of the project site, it was not possible for the researcher to check the instruments. Although local staff were monitoring other aspects of greenhouse operation, their technical knowledge was not sufficient to re-calibrate instruments. Since the instruments are still in Humla, it was not possible to verify if drift had occurred at the end of the experimental period. It would be expected however that this kind of instrument error would present itself as a gradual change in values rather than a step change that has occurred in this case.

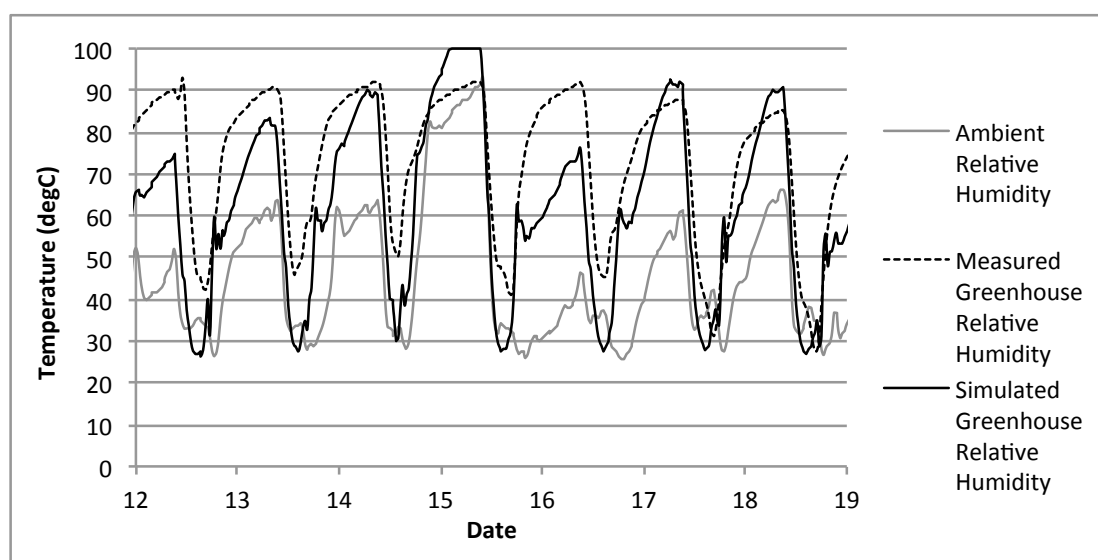


Figure 88 – Comparison of measured and simulated results for relative humidity with increased model humidity gain for March.

The optimal range for relative humidity varies for different crops, however a general range of between 50 – 70 % is considered optimal for plant growth (Vaisala 2011), with a maximum of 90% to reduce risk of disease. These results suggest that a more complex humidity gain model and ventilation model would be required to determine if humidity conditions are optimal over the entire winter period. A reasonable model fit has been achieved, however, for the earlier winter period. For this reason, the following analysis of cost reduction strategies that maintain current greenhouse conditions will use simulated data from earlier in the winter period, pending a more comprehensive model or better data. It will also

focus on greenhouse air temperature since it is considered the most important factor in plant development.

8.3 Performance improvements and cost analysis

In this section three different design modifications are implemented successively to investigate their impact on greenhouse conditions and potential cost reduction. These include reducing the wall from a double to a single layer, simplifying the door construction from insulated to non-insulated and increasing the infiltration rate to investigate the potential effects of unskilled construction. The potential cost reduction of these strategies are then analysed and compared.

8.3.1 Reducing wall thickness

Since the sealed dry stone walls contain air pockets and have in-built insulation, the validated model was used to test the effect of reducing the walls to a single layer and removing the straw insulation. The results in Figure 89 show that there is very little difference between the double and single wall scenarios. The average temperature values over the early winter period differ by only 0.31°C between the baseline (double wall) scenario and the single wall case, with the largest instantaneous difference only 0.91°C . This suggests that the double walled greenhouse necessary for other mountain areas is not necessary for Humla, due to the slightly warmer climate and the inherent insulating effect of local construction methods.

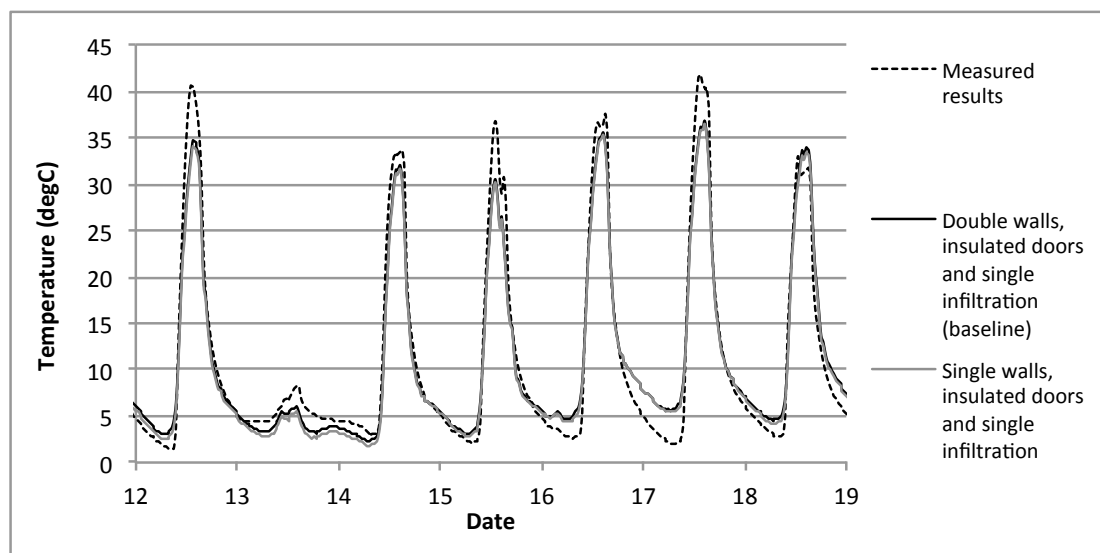


Figure 89 – Comparison of simulated greenhouse temperatures with single and double walls (baseline).

This would have a significant effect on the overall cost of the greenhouse, reducing the amount of materials needed and construction time. Wall construction comprised approximately 70% of skilled labour time, so a reduction in wall thickness by 50% would reduce the overall costs of construction by approximately 25%.

8.3.2 Un-insulated doors and vents

The greenhouse design incorporates wooden doors and vents insulated by a cavity filled with straw, and covered on the back with metal sheeting. To construct the doors and vents in this way requires more materials, particularly non-local materials that need to be transported to Humla, and longer construction time than a simple wooden construction. The validated model was used to investigate the effect of modifying the doors to a simple, single layer wood construction. Figure 90 shows that incorporating the simple, uninsulated doors and vents has little affect on the greenhouse air temperature, even when it is implemented in addition to single stone walls discussed previously. The average temperature values over the early winter period differ by only 0.32°C between the baseline scenario and this case, with the largest instantaneous difference only 0.92°C.

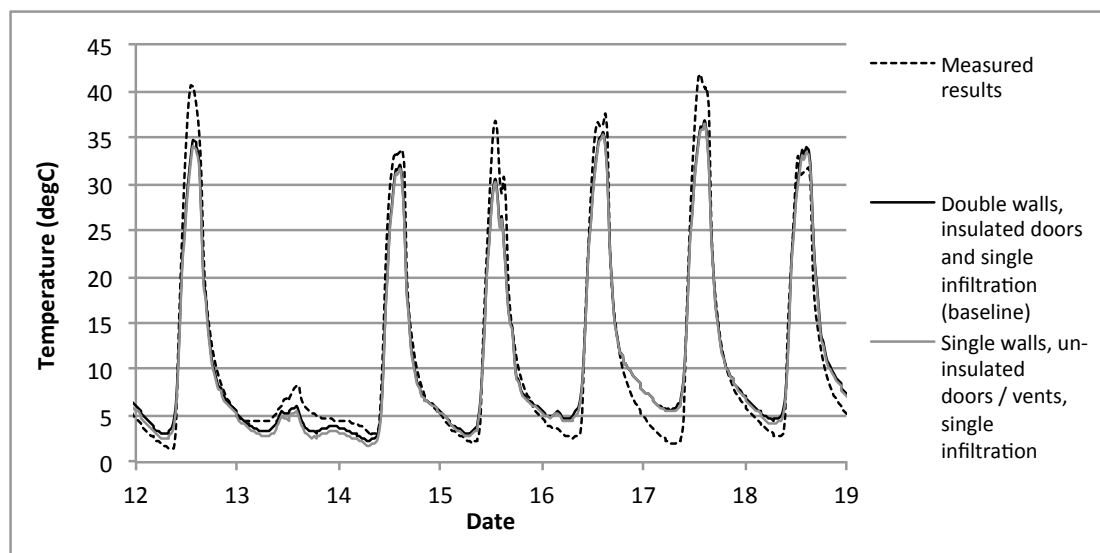


Figure 90 – Comparison of simulated greenhouse temperatures with single walls and non-insulated timber and double walls with insulated timber (baseline).

When the experimental greenhouse was built, it took approximately one day of skilled labour to construct the doors and vents, valued at 500 NPR. It is estimated that construction of these doors with unskilled labour would require two days of unskilled labour, valued at 300 NPR. It also cost 2376 NPR to purchase and transport the sheet metal. This means that implementing this design change would reduce the skilled and unskilled construction scenarios by 2876 NPR and 2676 NPR respectively.

8.3.3 Increased infiltration due to unskilled construction.

As mentioned in Chapter 6, it was decided to use local skilled labour to construct the experimental greenhouse to ensure the best possible results could be achieved within the criteria, which resulted in higher construction costs. An “unskilled” cost of construction was estimated based on lower labour costs and longer construction times. The validated model was used to explore the possible implications of unskilled construction via an increased infiltration rate, assuming a more leaky greenhouse. The results are shown in Figure 91 below.

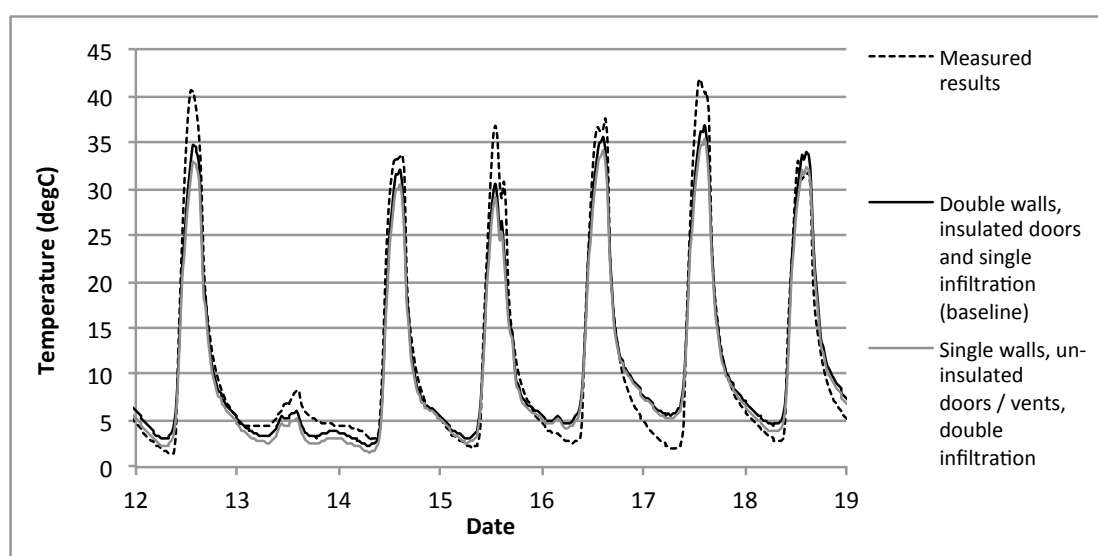


Figure 91 – Comparison of simulated greenhouse temperatures with single walls, non-insulated timber and double infiltration, and baseline scenario.

Again, the results show very little difference in measured and simulated temperatures. The average temperature values over the early winter period differ by only 0.69°C between the baseline scenario and this case, with the largest instantaneous difference only 2.6°C. This is greater than in the two previous scenarios, but not large compared to the range of greenhouse air temperatures.

The design changes proposed would also either have little effect on relative humidity (given the small temperature change) or could potentially reduce the humidity from increased infiltration, which would bring it closer to the desired range stated in the performance criteria. Given that the experimental greenhouse has not suffered adverse effects indicative of high humidity, it can be assumed that this modified version would perform equally or better than the current design. According to the estimated construction costs calculated in Chapter 6, using unskilled labour to build the greenhouse could reduce construction costs by up to 30%.

8.3.4 Cost analysis

Figure 92 shows the reduction of costs of greenhouse construction as each scenario is incorporated. As mentioned previously, the unskilled scenario alone would reduce the cost of the greenhouse from almost 90,000 NPR (\$US 1000) to less than 60,000 NPR (\$700). Incorporating single walls (assuming skilled construction) would reduce the overall cost by a similar amount, and a simple door and vent construction would reduce that figure by a further 5%.

The effect of all the modifications, i.e. a greenhouse constructed with unskilled labour, single walls and simple door construction would reduce the overall effective cost of construction by more than 50%, from almost 90,000 NPR to just over 40,000 NPR (around \$450 AUD). This is a significant improvement and would make this design appropriate for use in Humla because it is within the affordability criteria. Since farmers would not have to pay for their own labour, and assuming they could source their own stone, the actual cost of the greenhouse would be around \$US 300.

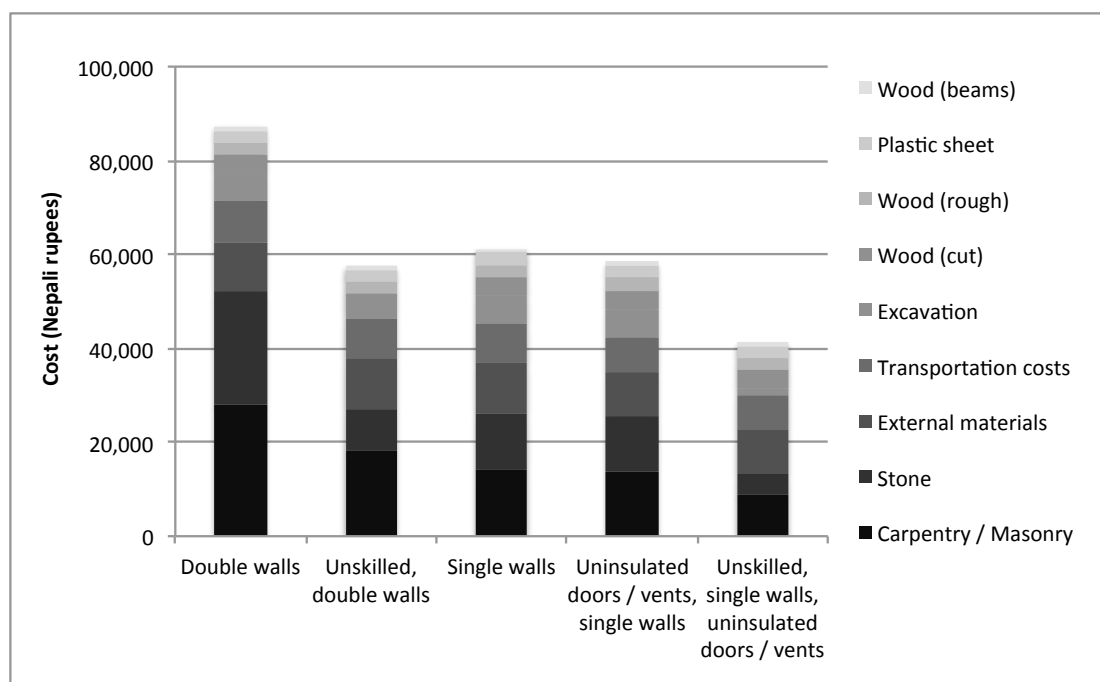


Figure 92 – Comparison of successive strategies for greenhouse construction cost reduction.

8.4 Summary and Conclusion

In this chapter, the structure of the greenhouse simulation model was described and the validation process outlined. Following this, the model was used to test different scenarios to reduce cost on the performance of the greenhouse. Finally, a cost analysis was presented comparing the cumulative effect of these scenarios on the overall cost of construction for the greenhouse.

The results from this chapter showed that it was possible to develop and validate a simulation model to predict how changes to the greenhouse structure and operation could affect indoor conditions. The input parameters that needed to be adjusted to improve the fit of the model included wall thermal properties, incident solar radiation on interior surfaces, radiation to the sky, humidity gain and infiltration. It was possible to determine if the greenhouse conditions would be within acceptable ranges of temperature and relative humidity, however for optimal plant growth, a more sophisticated humidity and ventilation model would be necessary. This would also require local wind data to be measured during the experimental process to more accurately predict natural ventilation. An overall conclusion is that using a validated model can allow design changes to be tested

without needing to construct another prototype, which would reduce the time that needed to be spent in remote areas.

The cost reduction strategies explored with the validated simulation model indicate that the successive modifications involving single walls and uninsulated doors and vents reduce the cost of construction by 30% without any significant change in greenhouse air temperature or humidity. In addition to this, the exploration of a scenario with increased infiltration showed that acceptable conditions could be maintained with a 'leaky' greenhouse or inferior construction, indicating that the potential "unskilled" greenhouse cost reduction calculation from Chapter 6 is valid. By incorporating all the cost reduction strategies, it was possible to reduce the cost of the greenhouse by more than 50% overall, which satisfied affordability criteria making this design appropriate for use in Humla. These results will be discussed further in the context of the entire research project in the following discussion (Chapter 9), from which conclusions will be drawn and recommendations made in Chapter 10.

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Chapter 9

Discussion

9 Discussion

Chapters 6, 7 and 8 set out the results of experimentation and modelling processes for the greenhouse and solar dryer. Some discussion was included in these chapters but this only related to specific aspects of the overall problem. The research question involves answering whether appropriate technologies, namely greenhouses and solar dryers, can be used together to improve nutritional intakes in Humla. The integration of these technologies, incorporating the production of fresh food in winter and the preservation of excess food from the summer to address the imbalance in food availability throughout the year, is not something that has been attempted previously. To answer the research question, the results need to be discussed in the context of entire project. How these results relate to one another to address specified criteria is the main topic of this chapter. This discussion provides basis on which to draw formal conclusions in Chapter 10.

Before discussing results, the research method is first reviewed. Following this the scope of the research project and the criteria are outlined, to provide context for the discussion. The results are then discussed in relation to each other and to the criteria, after which the potential social environmental and nutritional impacts of the findings are presented. This is followed by a discussion of the implications of the results and an outline of the limitations of this research and areas for further work.

9.1 *Review of method*

The combination of experimentation and simulation was chosen as the method to investigate this problem since it was believed it would provide sufficient accuracy of results, reduce the time required to be testing in remote areas and because it would be transferable to other areas.

The linear programming model provided a framework within which the nutrient adequacy implications of crop type and growing area could easily be compared and updated based on input parameters. The same model could be used in other areas with different local crops if the nutrient levels and yields of the crops were known.

TRNSYS Type 56 was found to be suitable for modeling a high altitude greenhouse based on its existing structure and inherent flexibility for incorporating additional inputs. The building model alone was not sufficient to model aspects specific to a greenhouse structure, such as increased radiation to the sky, but it was possible to incorporate these aspects with other components in TRNSYS. Through the validation process, however, it was found that experimentation was still necessary because simulation alone would not have been able to account for uncertainties related to construction and operation.

Once validated, the model gave a good approximation of greenhouse conditions without the need to construct another prototype and test it over another winter season. It was also easy to modify and explore the effect of different building parameters in Type 56 through user interface, without the need for complex programming. Design changes could be implemented individually or simultaneously to explore coupled effects.

Overall, a total of six months was required for fieldwork and just over one year was required for modeling. This is much less than the reported ten years required for the pilot program in Ladakh. The results of the modeled design modifications however have not yet been verified, so definitive conclusions about the effectiveness of this method in reducing time spent in remote areas cannot yet be drawn.

9.2 Interpretation of results and criteria

As established in Chapter 4 (Research Design), addressing nutritional intake deficiencies in Humla with appropriate technology is a socio-technical problem, requiring an interdisciplinary, systems engineering approach. The systems engineering methodology is applied to individual sub-systems and to the overall problem. Although the main focus of the research is on technical aspects of the solutions, social and cultural factors have been applied as requirements and constraints. It is not intended as a comprehensive anthropological or nutritional survey, but rather an attempt to illustrate that technical solutions cannot work in isolation.

To measure the success of this, results have been compared against certain criteria. These include nutritional, performance and appropriateness criteria associated with the crop, performance and design sub-systems respectively, outlined in Chapter 4. Like the sub-systems themselves, these criteria are also inter-related and the extent to which proposed solutions address all criteria is a measure of overall success.

The nutritional criteria refer to the contribution of greenhouse and solar dryer in addressing prominent nutritional intake deficiencies. These include micronutrient deficiencies such as iron, vitamin C, vitamin A and zinc and macronutrient deficiencies such as protein and energy. It is acknowledged that nutritional deficiencies can be caused by a number of factors outside the scope of this investigation. The focus is therefore on increasing nutritional intake because this can be clearly related to crop output from the greenhouse and solar dryer. In measuring success, the nutritional criteria are an aim rather than a requirement, with the aim being to improve nutritional intakes rather than meet nutritional requirements.

The performance criteria relate to the conditions inside the greenhouse and solar dryer, namely air temperature and humidity. For the greenhouse this directly refers to growing conditions, while for the solar dryer this is related to getting the crop to safe storage moisture content in a reasonable amount of time and at a faster rate than that of sun drying. The performance criteria are related to the nutritional criteria, since it is assumed that adequate growing or drying conditions are required for the best crop output. These criteria are also an aim and not necessarily a requirement, if crop output is sufficient to improve nutrition.

The appropriateness criteria refer to ensuring that any technical solution can be constructed, operated and maintained using local materials (or materials that could be easily transported to the area) and expertise, local crops and at low cost. These relate to both the performance criteria and nutritional criteria, since choice of materials and crops will affect performance, crop output and available nutrients. The local aspects of these criteria are a requirement, due to the isolation of the Humla region and the need for sustainable, in-situ solutions. The cost aspect is an aim, with the intention to reduce the cost as much as possible while still maintaining performance and crop output. Palatability was also an aim

with the intention to provide crop diversity, but not at the expense of a poorer nutritional outcome.

Each technology will be discussed in reference to these criteria in the following section.

9.3 Nutrition improvement, performance, appropriateness and long term impacts

The original aim of this research project was to investigate the complimentary nature of greenhouse and solar dryer produce to improve nutrition intakes in Humla, while satisfying certain criteria outlined above. In this section, the results from the testing of these technologies, both experimental and simulated, are discussed with respect to these criteria to determine if they feasibly meet the individual criteria, and ultimately contribute to improving nutrition. In addition to this, long term nutritional benefits are discussed, along with additional social impacts and barriers to adoption.

As established in Chapter 2, Humla is a remote, impoverished region with accessibility problems and extreme weather conditions. As a result, any appropriate technological solution had to be constructed in-situ with largely local materials and expertise at low cost, operate using local resources and be able to withstand local conditions. At the same time, each technology had to meet certain performance requirements to provide adequate growing and drying conditions. The aim of the experimentation and modelling process was to determine if the chosen designs could satisfy these requirements. Initial designs had already been selected with these requirements in mind, and based on their successful use in other areas, but their suitability for Humla still needed to be verified.

9.3.1 Greenhouse

The chosen greenhouse design was based on the GERES/LEHO design used successfully in the Ladakh region in India over the past decade. It is promoted by ICIMOD as a generic, appropriate high altitude greenhouse design, which is considered suitable for all conditions in the Hindu-Kush Himalayan mountain region. A preliminary nutrition analysis showed that a greenhouse with a growing area of between 25 - 30m², producing a combination of swiss chard and a small amount of cauliflower, should be sufficient to meet the requirements for a typical

family for iron, vitamin A and vitamin C, partially addressing the nutritional criteria and addressing palatability criteria.

It was found that this design could be constructed successfully in Humla with some design modifications to suit local conditions. The most significant of these included: construction of walls using local dry stone technique instead of adobe brick, mortared stone or rammed earth, as suggested in the ICIMOD construction manual; double glazing of polyethylene film as recommended in an evaluation of an existing greenhouse in Humla and; sheet metal on the exterior of the insulated doors and vents instead of plywood, since it was locally available and easier to transport. Most materials were local except for the UV stabilised polyethylene film for the glazing (imported from India) sheet metal (purchased in Nepalgunj, south of Humla) and other miscellaneous items such as paint pigment, wood varnish, hinges and long nails. Once constructed, the greenhouse was then successfully operated and monitored by local NGO RIDS Nepal, showing that it can withstand local conditions and be maintained within available labour time.

Although necessary to meet appropriateness criteria, these design modifications had implications for performance and cost. In terms of performance, the greenhouse conditions did not meet the performance requirements of recommended air temperature ranges between 10 - 32°C. Experimental results showed that they ranged from 2 - 40°C. These results indicated that thermal properties of the dry stone walls were not equivalent to those of adobe brick, mortared stone or rammed earth used in the construction of other examples of this generic design in other mountain areas. Despite this, crop output was good and sufficient to address some of the nutritional deficiencies identified in the nutritional criteria as predicted. Experimental crop results showed that swiss chard failed to germinate, but the cauliflower yields were better than expected. A combination of cauliflower and spinach was found to be sufficient to fully address vitamin A and vitamin C requirements and 93% of iron requirements.

However, the suitability of the GERES design for Humla was compromised by the high cost of \$US 1000 overall. The main contributing factors to the high cost were found to be the cost and volume of stone required for the double walls and the skilled labour employed for construction. The decision was made to use skilled labour to produce the best possible greenhouse prototype for the given

conditions. The cost of an 'unskilled' construction scenario was estimated based on local unskilled labour costs and an estimation of additional construction time.

Since lower quality construction could affect greenhouse performance adversely, this scenario was explored along with other cost reduction strategies, such as single walls and uninsulated doors and vents, using a validated simulation model. The unskilled scenario was modelled by increasing the infiltration in the greenhouse, effectively making it more 'leaky'. It was found via simulation that the implementation of these cost reduction strategies had little effect on greenhouse performance, but reduced the cost significantly. The biggest savings came from single wall construction, which reduced overall construction costs by 30%. The 'unskilled' scenario reduced the overall costs by approximately 20% and uninsulated doors and vents scenario reduced the costs by approximately 5%. Overall, the effective cost of the greenhouse, taking into account the cost of labour and materials, would be approximately \$450. In reality, however, if the stone was gathered and labour performed by the farmers themselves, the total cost would be reduced to that required to purchase the remaining materials, approximately \$300. It should be noted that wood would still need to be purchased, since it is scarce and restrictions apply to harvesting timber in certain areas.

Further benefits of the uninsulated doors and vents scenario include eliminating the need and hassle associated with transporting some external materials to Humla. This is important because transportation is not only expensive, but also impossible during some periods of the year. In terms of construction time, the single wall scenario compliments the 'unskilled' scenario in that while the latter would result in a longer construction period, the former would reduce it.

9.3.2 Solar dryer

Based on considerations of material availability, cost and experience in other mountain areas, a small, direct, cabinet dryer, similar to the Brace type, was considered to be most appropriate for use in Humla. This design is used extensively in Mustang for the drying of apples, and has been widely used in other developing countries for small scale drying. It is also reported to be able to achieve high temperatures compared to other low cost designs such as tent dryers, which reduce drying times.

Preliminary investigations into the potential nutritional contribution of the solar dryer showed that nutritional improvement would be small and would not meet the remaining nutritional criteria. Apples were selected as a suitable crop based on their local availability and complimentary nutrient content compared to greenhouse crops. Based on assumptions regarding nutrient content of crops and labour required, it was found that a higher labour input was required for a much smaller nutritional benefit per kilogram of produce compared to the greenhouse. To address nutritional criteria not already met by the greenhouse produce, large amounts of apples would need to be dried, which would not be possible over the two month harvest period, because it coincides with the main summer grain harvest and available labour time is small. These conclusions were based on assumptions however, and needed to be verified with experimental results.

Two slightly different prototypes were successfully constructed and operated in Humla using local materials and expertise. Taking into account labour and materials, the dryer cost approximately 5000 NPR (approximately AUD \$55). This is comparable to the cost of other small-scale appropriate technologies, improved cooking stoves purchased by villagers for use in Humla. The subsidized cost of a stove is \$50, suggesting that this solar dryer design would be affordable for local people.

In terms of performance, it is required that the crop be dried to safe storage moisture content of 0.28 (wet basis). The drying rate needed to be high enough so that the samples dried sufficiently before they spoiled and also be higher than that required to sun dry the crop under the same ambient conditions, to justify investing in a solar dryer. Preliminary tests of the solar dryer design in Australia were successful and produced reasonable drying rates. Samples were dried to safe storage moisture content within 2 – 4 days. When tested in Humla, however, results were not good. Only in one instance was the crop dried all the way to safe storage moisture content, after a period of five days. Other tests were interrupted with wet conditions or had very low drying rates due to high ambient humidity, so the samples spoiled before drying sufficiently for storage. This suggests that higher drying rates are required so that drying can be completed between rain events.

Although drying rates varied across trays, in all tests the average drying rate with the solar dryer was either the same or only marginally better than that with

traditional sun drying. Average temperatures inside the dryer were between 30 – 40°C, which is much lower than the recommend 50-60°C for agricultural crops. Even though solar drying has other significant benefits over sun drying, such as cleaner produce, drying rates would most likely be the factor to influence decisions by farmers to invest in the technology.

9.3.3 Combined nutritional improvement

The original aim was to investigate if the combination of greenhouses and solar dryers could be used to address selected nutritional intake deficiencies in Humla. It was intended that dried crops from the solar dryer and fresh crops from the greenhouse would compliment each other in terms of nutritional content.

The greenhouse produce was found to be able to adequately address vitamin C, vitamin A and iron intake deficiencies, and improve protein intakes. It was not able however to address zinc or energy requirements. In general, local crops that could be grown in the greenhouse or dried in the dryer were not high in zinc. In terms of energy requirements, locally available vegetable crops that are high in energy and can be grown in a greenhouse, such as corn, are not high in other specified nutrients. Based on general field data from Nepal, they also have low yields per square metre. The exception to this is carrot, which is high in both energy and micronutrients. It was found, however, that carrot did not grow well in the greenhouse. These aspects suggest that it is not feasible to address energy deficiencies with greenhouse produce if the aim is to improve nutrition overall and while adhering to the “appropriateness” requirement for local crops.

Although the solar dryer crop was relatively high in energy, the results showed that sufficient amounts could not be dried to significantly contribute to improving nutrition within current constraints. Overall the apple crop had low nutrient density which, coupled with the higher labour required to harvest and dry the apples, meant that the solar drying would produce less nutritional benefit from the same amount of labour as the greenhouse. This is important in the Humla context, and in fact in any developing country context, because reducing labour allows time for education and income generation activities. These results suggest that dryers are only likely to be useful for contributing to diversity of diet or tradable goods rather than nutrition. Further development of the design is also

required before it can be promoted as a low risk technology. Overall, the nutrition criteria could be partially addressed, but by the greenhouse alone.

9.3.4 Potential long term impacts of research findings in Humla and barriers to adoption

The potential long term impacts of the implementation of these appropriate technologies for food security in Humla are both nutritional and social, which contribute in different ways to alleviating poverty.

It is well recognized that under-nutrition and micro-nutrient deficiencies contribute substantially to the global burden of disease (Ezzati et al. 2002). Under-nutrition reduces immunological capacity to defend against diseases, and diseases deplete and deprive the body of essential nutrients. As a result, poverty is exacerbated through lost wages, increased health care costs, and impaired intellectual development that can significantly reduce earning potential.

Addressing key nutrient deficiencies, such as vitamin A and iron, can assist with addressing a number of issues affecting an impoverished community such as Humla. The most obvious benefit of addressing vitamin A deficiency is in the prevention of eventual blindness (Rice, West & ed 2004). Less obvious, however, is the effect on general immunity to disease and mortality (Sommer & West 1996). Addressing vitamin A deficiency can reduce the susceptibility to and severity of disease, which is particularly applicable in villages in Humla where sanitary conditions are poor. Both of these aspects would have a serious impact on economic potential and general survival in a mountain environment.

Ample evidence indicates that iron deficiency is the principal cause of anemia, and that both anemia and iron deficiency decrease fitness and capacity for aerobic work by decreasing oxygen transport and respiratory efficiency in muscles (Beard 2001; Caulfield et al. 2006). In a strenuous, high altitude mountain environment such as Humla addressing iron deficiency would have significant impact on the ability of the local people to complete their daily manual tasks necessary for survival and potentially increasing economic productivity in the long term. Iron deficiency has long been associated with developmental delays, and iron supplementation studies have demonstrated improvements in cognitive function (Pollitt 1993). Addressing iron deficiency therefore also has the

potential to address educational outcomes, a significant factor in poverty alleviation. Producing green leafy vegetables as a source of iron has added benefits due to the vitamin C also present in the food, which aids iron absorption (Hallberg, Brune & Rossander 1989).

Addressing nutrient deficiencies with a decentralized, agricultural and community based approach rather than a centralized supplement program has added benefits in the long term with regards to food sovereignty and empowerment. The ability of a community to solve their food based problems and generally shape their own lives, leads to increased self-confidence, from which community empowerment follows (Underwood & Smitasiri 1999). This contributes to better development outcomes, as indicated by a growing body of evidence linking empowerment and development effectiveness (Narayan-Parker 2002).

Food and agricultural strategies to improve nutrition, however, are more complex than a supplement program, and are therefore subject to certain barriers to adoption. Improving nutrition through increased dietary diversity requires behavioural change in relation to food choices. The approach devised in this research was based around quantities and ingredients in the existing Humla diet at other times of the year, so it is not anticipated that too much behavioural change would be required. It was also intended that the greenhouse program would be implemented alongside existing non-formal education and nutrition programs run by RIDS Nepal, so increased availability of vegetables would be complemented by increased awareness of their value for nutrition.

The use of agricultural innovation to produce the food required for increased dietary diversity has potential barriers to adoption in terms of information dissemination, changes in agricultural practices and investment in infrastructure. Information about an innovation spreads through social interaction: as knowledge about an innovation accumulates, the uncertainty about an innovation is reduced and people are more likely to adopt. Investment in the infrastructure is determined by economic constraints, namely the perceived costs and benefits in the adoption of a new technology. Benefits and costs are a function of personality, socio-economic characteristics, and perceptions about risk. Over time, knowledge about the innovation accumulates and people adjust their perceptions about costs and benefits, which then promotes diffusion (Schreinemachers et al. 2009).

Examples presented in Chapter 3 indicate that information diffusion about the benefits of greenhouses is already taking place in Humla, with a number of basic plastic structures being erected by wealthier residents such as hotel owners. The greenhouse program is also supported and promoted by a local NGO that has implemented other technologies successfully in the past. The emphasis on local materials in the design of the greenhouse in this research would mean that most of the structural components could be gathered by local farmers at little cost, with only the plastic cover requiring significant monetary investment. This means that the economic investment would more likely be in the form of time and labour, rather than cash. In terms of maintenance, it is anticipated that the plastic cover would need to be replaced every 2-3 years, but the other materials can be expected to last for at least 8-10 years based on experiences from other areas (Stauffer et al. 2004). This shows that the acquisition of the plastic cover is an essential factor in ongoing greenhouse operation. In the past, importing the plastic was hindered due to the closing of the border with India due to the unstable political situation in Nepal. This has now settled somewhat, so it is not anticipated to be a problem in the future. Importation of the plastic into the Humla district itself could be affected by the cancellation of flights due to adverse weather, however, it is also possible to transport it overland by animal if necessary. The ongoing availability of water is not currently a problem, but could pose a potential risk in the future if rainfall patterns change and snow melt is reduced.

Even if all the barriers to adoption are overcome, it is not possible to know if the use of these technologies will be sustained over a number of years. Experience with the greenhouse prototype over a number of years has shown that it can withstand any extreme weather events that have occurred, but it is not clear if these will intensify in the future due to the effects of climate change. Irregular weather events have so far only affected field crops such as wheat and maize, but have not been significantly extreme to damage structures.

9.4 Implications for projects in other areas

One of the main implications from the findings of this research is that the generic high altitude greenhouse design, as promoted by GERES and ICIMOD, is not necessarily applicable for all mountain areas in developing countries as suggested in the published manual. In this particular instance it is due to differences in

climate and in construction methods, but this implication is relevant to any application of appropriate technology.

By definition, appropriate technologies are specifically designed to suit the local context in which they are operating. Promoting generic appropriate technology solutions goes against these principles. Existing designs successful in other areas should only be used as a starting point in the process of finding an appropriate solution rather than simply being transplanted into the new context. Some adaptation will always be necessary, therefore either a pilot program or simulation modelling, if modelling skills are available, are required.

When developing a new design or adapting an existing design, another clear implication from this research is that simulation alone is not sufficient to test modifications. Modelling can reduce the physical design iterations, which is useful if there is little time or money for fieldwork, but cannot replace experimentation in remote areas, particularly in areas where construction techniques are not well documented. Good simulation results are also reliant on having accurate ambient data because results will not be accurate if the input data is incorrect. Having good ambient data is also important in understanding the context in which the technologies must operate. If ambient data such as this was available for Humla, the approach to the solar dryer experimentation might have been very different.

Another implication from the modelling process was that the Type 56 building model needs additional inputs to account for radiation losses to the sky and requires the use of the geosurf parameter to account for incident solar radiation on interior surfaces when used to model a greenhouse. This is due to the large area of glazing not typical for normal buildings. The need for these additional inputs would apply to any structure with a high glazed to wall ratio.

9.5 Limitations of study and areas for further research

The limitations of this study are mainly related to the interdisciplinary nature of the project and the remote context in which the fieldwork was performed. Areas for further research relate to these specific aspects but also to assessing the appropriateness of agricultural or food based interventions to improve nutrition.

Although this research was mainly focused on the physical and technological aspects of the two technologies, many interdisciplinary aspects were involved in establishing the criteria, requirements and constraints and in generating the results. This meant that in some cases, they could not always be covered in great detail and were based on assumptions from information found in literature.

The nutrient content of foods was based on values found in literature and not actually tested, as this would have been difficult in the remote context and also because it was outside the core discipline of the researcher. It is possible that local soil properties and other physiological aspects could affect the nutrient levels.

The recommended nutritional intakes were based on worldwide standards and were not specific to Nepal or Humla. The recommended intakes for the Humla people could be more or less than these values, so it would be beneficial to devise local requirements.

The food availability survey that was used to determine current nutritional intakes was done by a local NGO and was possibly not sufficiently rigorous or extensive to meet academic standards. It was however, the only information available for the Humla District. Where possible, values were verified with those found in literature, but this was not possible for all the data. A more extensive survey covering more villages and seasons would be beneficial to determine the full extent of food insecurity in Humla.

The crops selected to determine the potential nutritional improvements were restricted to those locally grown and eaten. Other crops not currently grown in Humla could be better suited to addressing the nutritional deficiencies not met, such as zinc and energy. Pumpkin seeds, for example, are high in zinc but are not normally eaten in Humla. Peanuts are a warmer weather crop that is high in energy and could possibly be grown in the greenhouse considering the high air temperatures that were reached. Further research into both of these possibilities would be useful to determine if all nutrition criteria could be met with in-situ methods rather than supplementation programs.

It must be acknowledged that many factors contribute to poor nutrition. This research only addresses nutritional intake. There is no guarantee that increased

food availability will address deficiencies if other factors are present such as poor sanitation and lack of access to health facilities. The finding from this research will be used by local NGO RIDS Nepal to inform their practice as part of their nutrition program, which itself is part of a bigger holistic development program including improved sanitation practices.

The performance results for the solar dryer were based on testing during the harvest season, since there is currently no commonly used storage method for apples in Humla. Based on results from prior research, and on climate data it is possible that the solar dryer would perform better at a different time of year. Further research into basic cool stores could be beneficial to test if apples could be stored for a short period of time and then dried for longer storage, or if they could be stored for a longer period, negating the need for drying at all.

The experimental greenhouse was operated by local NGO staff over the test period. The solar dryer testing was performed by the researcher, but the solar dryer itself was also used successfully by local staff. Although some greenhouses and solar dryers are currently in use in Humla, these particular technologies have not yet been implemented with local families. Further monitoring is required to determine if the outputs would be similar. This monitoring would also be useful to verify the estimates made about the time required for operation and maintenance.

Although the design modifications were tested with a validated simulation model, they still need to be physically tested. This particularly applies to the unskilled labour construction scenario. A pilot program testing the modified design would be beneficial to test both the performance and the operation and maintenance requirements.

In terms of the choice of nutritional intervention, an approach based on improving nutrition through improved agricultural production was chosen for this project based on recommendations by the FAO and by success in other areas. However, it was not possible to compare the efficacy of this method to that of a supplementation program based on lack of data. Food-based strategies, particularly dietary diversification and the promotion of specific food groups for preventing micronutrient malnutrition, are less advanced than other programs. This is due to the fact that these strategies involve complex cultural and context

specific behavioural change that simpler strategies that involve supplement distribution. However, consensus is growing that improving dietary intakes through agricultural innovations and dietary diversification represents long-term answers to micronutrient malnutrition, but progress is slow because of the urgency of alleviating deficiencies in the short term. More research is needed to define the policies and methods that will promote these strategies.

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Chapter 10

Conclusion

10 Conclusion

The aim of this research was to investigate the potential for appropriate greenhouses and solar dryers to be used together to increase food availability and diversity, and improve intakes for prominent nutritional deficiencies in Humla. The aim was also to develop a transferable method that could be applied in other areas.

This research focused mainly on the performance and cost aspects of the greenhouse and solar dryer designs over winter and how they relate to crop production. Results were measured against nutritional criteria, namely the shortfall in required nutritional intakes for protein, zinc, energy, vitamin A, vitamin C and iron over the winter period, performance criteria, and “appropriateness” criteria, based on the definition of appropriate technology and affordability.

Based on appropriateness considerations and past research, a double walled, insulated lean-to style greenhouse and a small wooden direct box type dryer were selected. Both designs are widely used in other mountain areas and promoted as generic appropriate technologies. It was found that both the selected designs for the greenhouse and solar dryer could be constructed, with some modifications, and operated in Humla using local materials and expertise, largely satisfying appropriateness criteria.

The performance of the greenhouse was outside the recommended temperature ranges, indicating that the generic high altitude greenhouse design was not entirely appropriate for use in Humla. This was due to the fact that Humla has a slightly warmer climate than other mountain areas where this design is widely used and also because local construction methods, namely dry stone walls, have different thermal properties to mortared stone and adobe brick walls used in other areas.

Although the greenhouse did not satisfy performance criteria, crop production was still adequate to improve food availability and nutrition. Crops were selected based on nutrient content and whether they were locally available. A greenhouse with 25 m² of growing area, with spinach and cauliflower as the main crops, could

adequately address required nutritional intakes for vitamin C, vitamin A and improve protein and iron intakes for a typical poor family in Huml. It was found that zinc and energy requirements could not be addressed by greenhouse production while operating within the local crops constraint.

The cost of construction for the greenhouse was, however, very high. Using skilled labour the overall cost was around \$US 1000, which was double the \$US 500 specified in the affordability criteria and double the reported cost of construction of this design in other mountain areas. Although the high cost was partly due to the use of skilled labour to construct the greenhouse, it was also partly due to the labour intensive method of dry stone wall construction. Further investigation of design modifications with the validated simulation model showed that the wall thickness could be reduced from double insulated walls to single walls without affecting performance. This was thought to be possible due to the different thermal properties of dry stone walls. This result implies that the generic, appropriate high altitude greenhouse design is not necessarily applicable in all mountain areas since climate and construction methods can vary.

Simulation results also showed that either removing insulation from the door and vents or increased infiltration would not affect performance. The latter result is significant because it shows that inferior construction will not significantly affect performance, so unskilled labour could be employed to construct the greenhouse. This would greatly reduce the costs involved. Overall, with all the above modifications, the effective cost of the greenhouse would be reduced to \$US 450, which satisfies the affordability criteria. Since farmers would not have to pay for their own labour and could gather their own stone, the actual cost of the greenhouse would be around \$US 300.

The solar dryer could be constructed for around \$US 50, which satisfied affordability criteria, but was found to not perform well in Humla. Performance criteria, namely that the samples should be dried to safe storage moisture content before spoiling and at a faster rate than that of sun drying, were satisfied, but only narrowly and not consistently. Although there are other advantages of solar drying over traditional sun drying, a faster drying rate would be the main factor to justify investment in a solar dryer by local people.

In addition to this, the produce from the solar dryer was found to contribute little to improving nutrition compared to that of the greenhouse. Apples were selected based on local availability and nutrient levels that complimented the selected greenhouse crops, namely that they were high in energy. The overall nutrient density was significantly lower than greenhouse crops, while the labour involved in drying the apples was higher. Through comparison using the linear programming model, it was found that the same or better nutritional outcome could be achieved with the greenhouse produce with less labour time. This is important in the Humla context, and in fact in any developing country context, because reducing labour allows time for education and income generation activities.

Although the solar dryer satisfied the affordability and appropriateness criteria, its poor performance and minimal contribution to improving nutrition means that this design is not considered appropriate for improving nutrition in Humla under current constraints. The greenhouse performed sufficiently well to produce enough crops to potentially address some nutritional intakes. Although the initial cost was high, it is thought that modifications could be made to reduce this and therefore this design is considered to be appropriate for use in Humla. Overall, food availability was improved and nutritional criteria were partially satisfied.

The combination of experimentation and simulation was found to provide accurate and timely results, and enable easy comparison of design and crop alternatives. The linear programming model provided a framework within which the nutrient adequacy implications of crop type and growing area could easily be compared and updated based on input parameters. TRNSYS Type 56 was found to be suitable for modeling a high altitude greenhouse based on its existing structure and inherent flexibility for incorporating additional inputs. Through the validation process, it was found that experimentation was still necessary because simulation alone would not have been able to account for various uncertainties. Due to the nature of each model used, this method can be applied to different contexts by just changing the input parameters meaning that it is transferable. Overall, a total of six months was required for fieldwork and just over one year for modeling. This is much less than the reported ten years required for the greenhouse pilot program in Ladakh. The results of the modeled design modifications however have not yet been verified, so definitive conclusions about the effectiveness of this method cannot yet be drawn.

Some of these conclusions are based on assumptions that need to be verified with further research. This includes investigation into the thermal properties of dry stone walls and experimental investigation to validate the performance and cost implications of the simulated design modifications, particularly the case where the greenhouse is constructed with unskilled labour. Further research into the long-term effects of these technologies on diet and nutritional status of the local people would also be useful to determine the physiological effects of increased food production. The efficacy of food based strategies such as this, compared to widely used supplementation programs, also needs to be explored to support the growing consensus that that improving dietary intakes through agricultural innovations and dietary diversification could provide long-term answers to micronutrient malnutrition and other aspects, such as as empowerment that are associated with alleviating poverty.

Appendix 1

Design, Construction and Testing of drying oven to determine initial moisture content of crops

Appendix 1 - Design, construction and testing of a drying oven to determine initial moisture content of crops

Drying is a common and popular method used throughout the world to preserve agricultural produce and, in some cases, increase their value. Sun drying, where crops are simply laid out on a suitable surface in the sun, is the most widely practiced form of drying, particularly in developing countries. It is cheap, easy and convenient but has disadvantages in that the crop can be easily contaminated, stolen or slowly and irregularly dried. These problems can be reduced using a solar dryer, a structure that enhances the drying power of the sun and protects the crop. The uptake of solar drying however has not been widespread, which according to Battock (1990) is due to the fact that dryers require capital to build, that is not necessarily translated into increased value or efficiency. As a result, solar dryers are a common sight at research centres, but are rarely found on a farm. This suggests that more in-situ solar dryer research is required to take into account the wider socio-economic context in which they must operate. When testing the efficacy of a solar dryer for a particular crop, it is first necessary to determine the dry matter content. This value is used to determine the initial moisture content and the point in the drying process when the safe storage moisture content has been reached. The standard procedure to achieve this involves drying a fresh sample of the crop in a drying oven for an extended period of time at a set temperature. Once all moisture is removed, the remaining dry matter can be weighed and the initial moisture content calculated. Since moisture contents of vegetables and fruit vary according to type and location, for accuracy it is necessary to determine the specific moisture content of the crop to be dried.

When testing in a remote area in a developing country, however, no drying oven facilities are available and it is not feasible, and sometimes impossible, to transport fresh samples to a laboratory with an oven. The aim of this paper is to describe the development of a small portable drying oven to determine the dry matter content of local crops in-situ in Humla, a remote mountain district in Nepal. This information will be used to determine the efficacy of a locally constructed solar cabinet dryer, which is being tested as part of a larger research project investigating the use of appropriate technology to improve food availability in the area.

Section A 1.1 describes the oven design, including materials and cost. The experimental procedure is presented in Section A 1.2, followed by the results in Section A 1.3. Brief conclusions and recommendations for improvement are made in Section A 1.4.

A 1.1 Oven Design

When designing a drying oven for use in Humla, certain requirements and constraints need to be taken into account. This region has no road access and all research equipment has to be transported in by plane or overland, so it is preferable for the drying oven to be small enough to fit in a suitcase or bag. Electricity is available, but it is supplied via a stand-alone solar system, so low power usage is a requirement for the oven.

An oven prototype was constructed at the High Altitude Research Station (HARS), which is maintained by a local non-government organisation, Rural Integrated Development Services (RIDS). It is situated in Simikot, the main village in Humla, at an altitude of 3000 m (Figure A1).



Figure A1 – Simikot village and surrounding mountains.

The oven consisted of two cylindrical tins of different diameters (Figure A2). One tin was nested inside the other, so that the air gap provided insulation. The inner and outer tins had diameters of 7 cm and 12 cm respectively. A 40W light globe was used as the heat source in the inner tin. Inlet and outlet air vents were situated at the top and bottom of the oven respectively, passing through the outer tin to the inner tin, and sealed with self-adhesive putty (i.e. Blu-Tack). The outlet vent was attached to the lids of both tins, which could be removed to insert the samples.

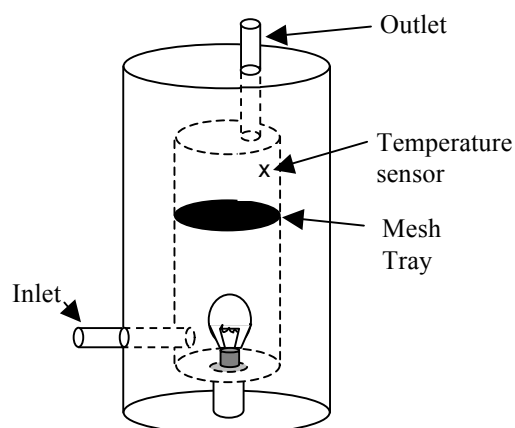


Figure A2 - Portable electric drying oven

A mesh tray was installed inside the inner tin to hold the sample, directly above the light globe. A manual dimmer switch was used to vary the power for the light globe to keep the temperature constant inside the oven. Most materials were sourced at a hardware store in Australia, apart from the tins which were leftover food containers. The oven cost around \$10 AUD and took two hours to assemble.

A 1.2 Method

The Association of Official Analytical Chemists (AOAC) have published an official method for determining the moisture content of fresh and dried fruit (AOAC 1980) which will be used as a basis for the method used in this investigation. Due to the lack of some equipment, this AOAC procedure had to be modified slightly for use in Humla.

To prepare the sample for drying, the AOAC method states that a sample of the fresh fruit must first be passed through a mincer twice and mixed thoroughly. Following this, a portion of this mixture must be weighed (to the nearest 0.02g) and mixed with asbestos (2 g asbestos to 5 g of fruit) and a little water. No mincer is available in Humla, so the sample was chopped and mashed as finely as possible with a sharp knife. In addition to this, no asbestos is available to mix with the sample. According to the method published by the United Nations Economic Commission for Europe (UNECE 1998) for determining the moisture content of apples (which is based on the AOAC method), it is possible to use dried sand washed with hydrochloric acid in place of the asbestos. This material is not available either, so it was decided to dry the mashed sample alone.

Once prepared, the sample was placed in a metal dish. The AOAC method states that this dish must be made of corrosion resistant metal and have a tight fitting lid. A small tin was used for this purpose and weighed in advance with the lid to the nearest 0.01g. The sample and open dish / tin was heated on a boiling water bath (bain-marie or steam-bath) to evaporate the water to dryness. The dish was then placed in the

oven, with the lid alongside it, and dried for 6 hours. The AOAC method states the sample must be dried for this period at $70^{\circ}\text{C} \pm 1^{\circ}\text{C}$ under a pressure not exceeding 100 mm Hg, during which time the oven should not be opened. Due to the configuration of the oven designed for use in Humla, it was necessary to put the sample inside the oven without pre-heating, so the dry period included a warming-up stage when the temperatures inside the oven rose from room temperature to 70°C .

The AOAC method states that during drying, a slow current of air (approximately two bubbles per second) should be admitted, with the air having been dried by passing through H_2SO_4 . Unfortunately, neither an airflow regulator nor H_2SO_4 are available in Humla. Airflow was regulated via natural ventilation and small inlet and outlet pipes at the top and bottom of the oven (see Figure A2).

After drying, the dish is supposed to be removed from the oven, covered immediately with the lid and placed in a desiccator to cool to ambient temperature. No desiccator is available in Humla, so the sealed tin was instead placed in a bowl of uncooked rice, which is commonly known as a basic desiccant and widely available in Humla since it is one of the main ingredient in local meals. Once cooled, the covered dish was weighed to the nearest 0.01g.

The moisture content (MC) of the sample, as percentage by mass is calculated as follows:

$$MC = \frac{M_1 - M_2}{M_1 - M_0} \times 100 \quad \text{Eq. A1}$$

where: M_0 = mass of the empty dish with lid.
 M_1 = mass of the dish with lid and test portion before drying.
 M_2 = mass of the dish with lid and test portion after drying.

Two oven tests were performed in September 2009. The air temperature inside the oven (inner tin) was monitored with a TMC6-HD temperature sensor, connected to a Hobo H12 data logger, which was used to measure the ambient temperature. Temperature changes were measured once every minute. The temperature was regulated manually. The data logger was connected to a computer so that temperatures could be monitored as they were recorded via a visual interface. The power to the light globe was adjusted via the dimmer switch in response to increases or decreases in oven temperature. All samples were weighed with an HF 2000G electric weighing scale (A & D Company Ltd).

A 1.3 - Results

Figure A3 and Figure A4 show the temperature readings in the oven during the first and second tests respectively.

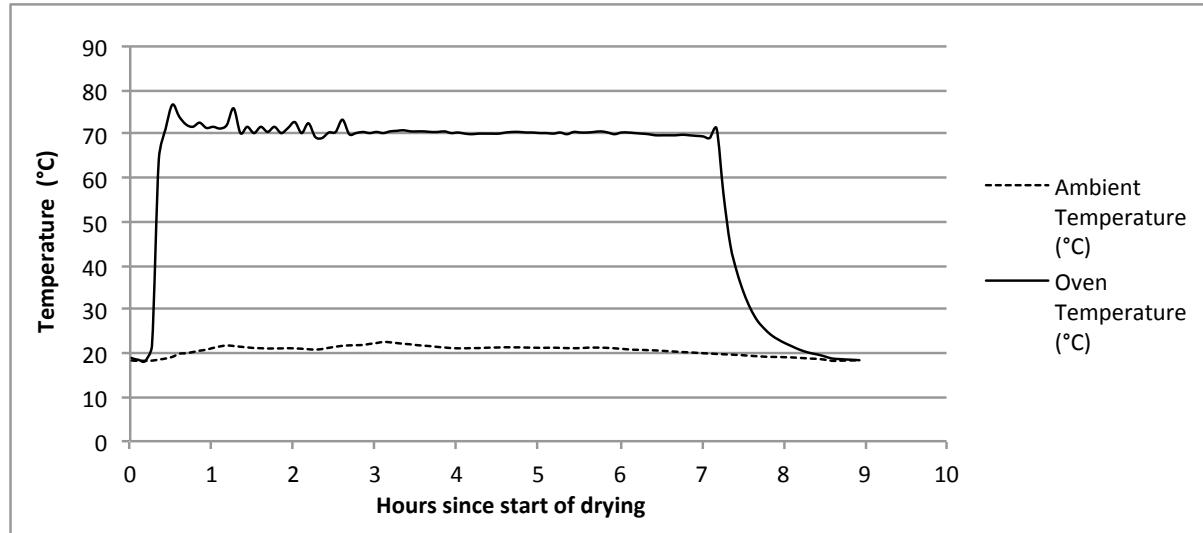


Figure A3 – Drying oven temperatures during first test.

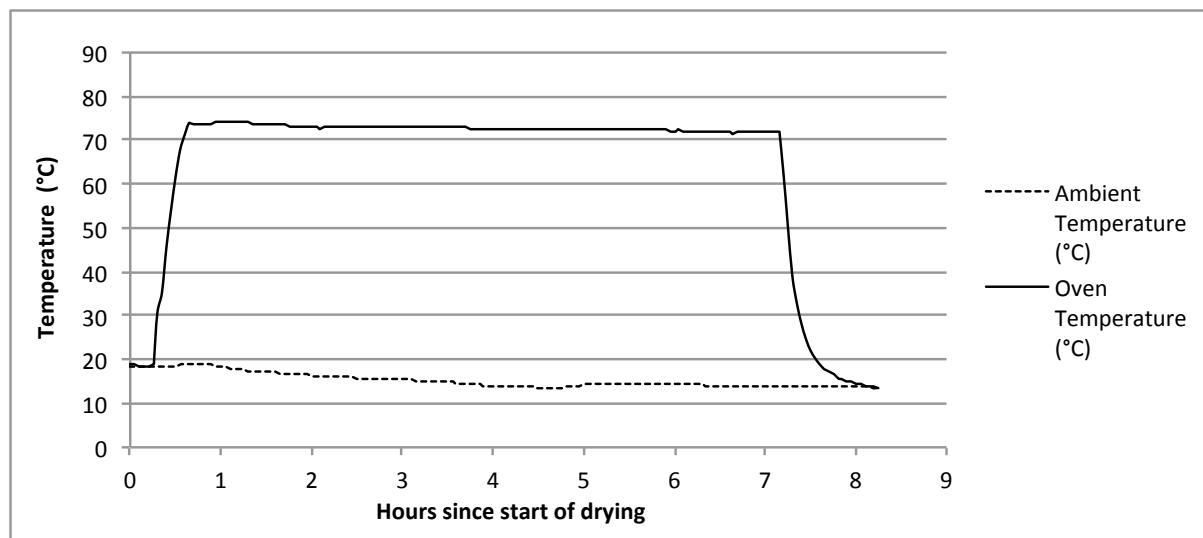


Figure A4 – Drying oven temperatures during second test.

Table A1 shows the mean and standard deviation of the oven temperatures for each test. The data used was from the period when the oven first reached 70°C until the point when the power was switched off and the oven allowed to cool down.

Table A1 – Mean and standard deviation of oven temperatures.

Test number	Mean Oven Temperature (°C)	Standard deviation (°C)
1	70.73	1.25
2	72.81	0.65

The drying standard states that the oven temperature should remain within $\pm 1^\circ$ of 70°C for 6 hours. Due to the simplicity of the equipment it was not possible to maintain this temperature range. During the first test, the oven temperature was outside this range 23.2% of the time and during the second test it was outside this range 100% of the time. During the second test, however, the standard deviation was low, even though the mean temperature was higher than 70°C . It can be seen in Figure A4 that a consistent temperature was maintained that was 2-3 $^\circ\text{C}$ above the required temperature.

However, if a slightly wider range ($\pm 4^\circ\text{C}$) is considered, the results are more favourable. During the first test, the oven temperature was outside this range only 3.7% of the time and for the second test it was only outside this range 19.4% of the time. This indicates that the oven temperature was not too far outside the $\pm 1^\circ$ range and was the best that could be achieved under the circumstances. Oven temperature was regulated manually, so it is possible that better results could be achieved with an automated system.

The dry matter results from the drying oven tests were used to determine the initial moisture content of the apple samples and are shown below in Table A2. According to the AOAC standard (AOAC 1980), duplicate determinations of moisture content should agree to within 0.2%. These results are outside this range, however they are within the range of 80.9 - 89.6% found in literature and are close to the most commonly stated moisture content of 84% for apples (Duke 1992; Salunkhe 1974).

Table A2 – Results of drying oven tests

Test No.	Initial weight of sample (g)	Final weight of sample (g)	Moisture content (%wb)
1	15.3	2.55	83.3
2	14.9	2.24	85.0

A 1.4 Conclusion

The results of this investigation show that it is possible to build a small portable drying oven for use in solar dryer research in remote areas. With this oven it was possible to reach and maintain a mean oven temperature of 70°C or higher, with a standard deviation of less than 1.5°C. The temperature variation was outside the required $\pm 1^\circ$, so a better temperature regulation system is required. Although variations to the method to determine moisture content were required to suit the local context, results were achieved that agreed with those stated in literature. The results of separate tests, however, did not agree to within the required tolerance. This indicates that more tests would be required in future investigations.

A 1.5 References

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