UNDERSTANDING AGRICULTURAL INNOVATION ADOPTION PROCESSES AND GARDEN SCALE WATER USE THROUGH FARMER-DRIVEN EXPERIMENTATION

MSc THESIS

By

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ABSTRACT

A holistic approach to agricultural innovation development and extension is needed to address both socio-economic and biophysical dynamics that influence adoption and dissemination of innovations. This thesis presents a methodology for involving South African subsistence farmers in the process of innovation development through facilitation of farmer-driven gardening experiments. Farmer-driven experimentation allows farmers to methodically assess the value of innovations they choose to study while providing researchers with a venue for learning about socio-economic as well as biophysical influences on farmers' decisions.

In addition to learning about adoption processes through farmer-driven experimentation, researchers were able to use farmers' manually collected data and observations to supplement laboratory generated and electronically recorded information about soil water dynamics associated with different garden bed designs and irrigation strategies. Compared to control beds, trench bed soil samples showed decreased acidity and increased phosphorus in the rooting zone. In addition, trench beds appeared to retain more moisture throughout the soil profile than control beds during wetter months, including short dry spells spanning up to 6 days. However, gradual but increases in soil water tension were recorded in trench bed soils during prolonged dry spells, possibly as a result of high connectivity between pore spaces in the trench beds, combined with evapotranspiration associated with vegetation cover. Water harvesting with run-on ditches showed increased water infiltration to depths of 80 cm, compared to a control bed during consistent rains. However, during a series of prolonged dry spells, soil in the run-on ditch bed began to lose moisture notably at all depths, while soils in the control lost moisture at a more gradual rate. This may have been a result of evapotranspiration at the run-on ditch bed associated with heavy vegetation cover as well as evaporation through ditch sidewalls surrounding the bed. Drip irrigation was found to be impractical because the available drip kits were prone to malfunction. Wetting Front Detectors were shown to have some potential as management tools for farmers, provided certain limitations such as availability are addressed. To fully realize their potential in subsistence farming, farmers and researchers need to engage in discussions, demonstrations and experiments related to the movement of water within the soil

profile, such as rooting depth and its relation to wetting fronts as well as its significance in terms of plant production.

Farmers participating in a series of monthly, hands-on workshops that encouraged individual experimentation tended to adopt and sustain use of many introduced garden innovations. Farmers who were also involved in a formalized research and experimentation process at their own homesteads became more proficient with gardening systems in general, through continual trial-and-error comparisons and making decisions based on observations, than those who were not involved. This suggests that the practice of on-going experimentation, once established, reaches beyond the limits of facilitation by researchers or extension agents, into the realm of sustainable change and livelihood improvement through adoption, adaptation and dissemination of agricultural innovations.

While farmer-driven experimentation does limit the control a researcher may have over an experiment and Participatory Learning and Action research is more time intensive than traditional research, these are outweighed by the immediate benefit of aligning innovation development with the socio-economic as well as biophysical conditions present within the community targeted for innovation adoption. It empowers the farmers whose livelihood improvement is often the goal of agricultural research. The result is an innovation farmers understand how to operate and explain to others and that is suitable to local conditions. In other words, an innovation that is more readily adopted, adapted and disseminated.

PREFACE

The experimental work described in this thesis was carried out in the School of Bio-resources Engineering & Environmental Hydrology, University of Kwa-Zulu Natal, Pietermaritzburg, from August 2006 to May 2008, under the supervision of Professor Graham P.W. Jewitt.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

DECLARATION 1 - PLAGIARISM

I, Jody Dawn Sturdy declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a. Their words have been re-written but the general information attributed to them has been referenced
   b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.

5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed:

Jody D. Sturdy

DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication)

Publication 1 – Chapter Two of this Thesis

Sturdy, J.D., Jewitt, G.P.W., Lorentz, S.A., submitted. Building an understanding of water use innovation adoption processes through farmer-driven experimentation. *Physics and Chemistry of the Earth.*

Research for this publication was conducted by J.D.Sturdy with technical advice from G.P.W.Jewitt and S.A. Lorentz. This publication was written in its entirety by J.D.Sturdy and all data tables, graphs and photos were produced by the same, unless otherwise referenced in the text of the paper. Editing and advice regarding data interpretation was provided by both G.P.W.Jewitt and S.A. Lorentz.

Publication 2 – Chapter Three of this Thesis

Sturdy, J.D., Jewitt, G.P.W., Lorentz, S.A., in preparation. Participatory evaluation of soil water movement with differing garden bed designs and irrigation practices. School of Bio-resources Engineering & Environmental Hydrology, University of Kwa-Zulu Natal, Scottsville, South Africa. For submission to *Water South Africa*.

Research for this publication was conducted by J.D.Sturdy with technical advice from G.P.W. Jewitt and S.A. Lorentz. This publication was written in its entirety by J.D.Sturdy and all data tables, graphs and photos were produced by the same, unless otherwise referenced in the text of the paper. Editing and advice regarding data interpretation was provided by both G.P.W.Jewitt and S.A. Lorentz. S.A.Lorentz created the original spreadsheet that was used to generate soil hydraulic characterization graphs, Figures 3.10 and 3.12, and wrote a brief interpretation of these figures, some of which was paraphrased in section 3.2 of the "Second Publishable Paper" (Chapter Three) presented in this thesis.

Publication 3

Kruger, E., Sturdy, J.D., deLange, M., 2008. Feeding and watering the soil to increase food production. *LEISA Magazine* 24(2):20-21. Available from: http://www.leisa.info/index.php?url=getblob.php&o_id=209101&a_id=211&a_seq=0. [Accessed: 22 June 2008].

Research for this publication was conducted by E. Kruger and J.D. Sturdy. The publication was written by E. Kruger with editing and technical advice provided by J.D.

Sturdy and M. deLange. The cover photograph was taken by J.D. Sturdy and the same photograph has been annotated for use in the "Second Publishable Paper", Chapter Three, of this thesis. No data tables or graphs are provided in this publication, however, the publication does outline some of the Participatory Learning and Action research methods employed during research for this thesis. Interview results given in this publication are from surveys conducted by E. Kruger and others, not by the author of this thesis. Where these results are referenced in this thesis the sources are cited. Interpretations of trench bed data in this publication were paraphrased by E. Kruger from the "Second Publishable Paper", Chapter Three, of this thesis and do not fully encompass the data and interpretation presented in this thesis.

Signed:

Jody D. Sturdy

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CHAPTER THREE

Second Publishable Paper:
Participatory evaluation of soil water movement with differing garden bed designs and irrigation practices

CHAPTER FOUR

LIST OF ABBREVIATIONS & SYMBOLS

θ	-	Water content
ARC	-	Agricultural Research Council
BEEH-UKZN	-	Bio-resources Engineering & Environmental Hydrology, Univerity of KwaZulu-Natal
C_1 & C_2	-	Soil property constants
c	-	propagation velocity of electrical signal in a vacuum
D	-	Drainage
DWAF	-	Department of Water Affairs and Forestry, RSA
Ec	-	transpiration
Es	-	Evaporation (from soil and interception)
ET	-	Evapotranspiration
FLW	-	Farmer Learning Workshop
K_a	-	Apparent dielectric constant
L	-	Length
PLA	-	Participatory Learning and Action
R	-	Rainfall
Roff	-	surface runoff
RSA	-	Republic of South Africa
SSA	-	Sub-Saharan Africa
SSI	-	Smallholder System Innovations in Integrated Watershed Management program
t	-	Time
V	-	Velocity
WFD	-	Wetting Front Detector
WMS	-	Watermark® sensors
WP	-	Water Productivity
WSI	-	Water System Innovation
WUA	-	Water User Association
WUE	-	Water Use Efficiency
z	-	depth

CHAPTER ONE

Introduction and Literature Review

1. INTRODUCTION

World poverty eradication depends largely on the ability of mankind to develop and implement sustainable methods for producing and distributing sufficient food supplies across the globe. This will require improved water productivity because, as Postel (1999) suggested, water scarcity poses the greatest threat to global food production. In the shadow of a rapidly increasing population (United Nations Statistics Division, 2005), the United Nation's World Food Summit (1996) set a goal of reducing the 800 million food insecure people to half by the year 2015. The Summit outlined several factors that must be addressed in order to reach this goal, including the mitigation of seasonal instability in food supplies. To address this issue they called for the transfer and utilization of agricultural technologies (innovations) as a means for conservation and sustainable use of biodiversity. In Africa, where only 60% of the population have access to healthy water and the number of undernourished is over 200 million (Wright *et al*., 2002), such innovations have significant potential for improving livelihoods.

A majority of the population in sub-Saharan Africa (SSA) depend to a great extent on rain-fed, subsistence agriculture for their livelihood security (Rockström, 2000). Intensification of crop production on smallholder farms is needed in order to provide sufficient food availability for an increasing population, which is vital for reduction of poverty and malnutrition. However, this intensification should be developed using sustainable levels of external input (technology, funding and policy) combined with local knowledge and resources (Smith *et al*., 2004). This suggests that decisions aimed at increasing small scale farm productivity must consider the tradeoffs between the various socio-economic and biophysical objectives involved. Hence, sustainable increase in crop production (including vegetable gardening) requires an interdisciplinary approach to developing agricultural system innovations. To attain an adequate level of interdisciplinary integration, Kropff *et al*. (2001) stress the importance of utilizing knowledge derived from model-simulations and scientific measurements, in conjunction with expert knowledge that includes stakeholder expertise. They further claim that computer simulations and mathematical models provide objective tools for determining biophysical consequences of resource management decisions, but that a complete systems assessment must be complimented by socio-economic analyses before it can truly be beneficial.

In order to address the social aspects of agricultural development effectively, farmers' own capacities and priorities must be incorporated into the development process. This should be done in a way that integrates socio-cultural, political and economic dimensions of innovation, application and transfer of knowledge within and between rural communities and scientific organizations (Scoones and Thompson, 1994). The "Beyond Farmer First" approach to development addresses these dimensions by assuming that stakeholders have differentiated interests, goals, power and access to resources, and that knowledge of a given agricultural system is generally diffuse and fragmentary. Hence, development processes must involve bridging, accommodation, negotiation and conflict mediation between stakeholders. Process learning takes place through dynamic and adaptive implementation of negotiated outcomes. Development work should be a collaborative process of learning and action that involves dialogue and empowerment. In this process of learning and action, the researcher's role is that of facilitator, initiator or catalyst. The farmer's role is that of creative investigator and active analyst (Scoones and Thompson, 1994).

1.1 Problem Statement

Smallholder farmers in semi-arid regions of South Africa are faced with the significant task of sustaining their own livelihoods through agricultural productivity. The lands they are working, and the climate they are subject to, require agricultural practices that specifically address the issues of poor rainfall distribution and partitioning, in order to produce adequate crop yields for commercial sales and even for subsistence (Rockström, 2000; Rockström, 2003).

The social and ecological resilience of many smallholder communities in South Africa is relatively low because, among other reasons, farming and grazing practices have resulted in low biodiversity and high land degradation. While resilience can be increased in a variety of ways, one of the primary means of doing so in rainfed agricultural systems is by bolstering water productivity (WP – crop output per cubic metre of water) through use of innovative technologies (Oweis and Hachum, 2006; Rockström, 2003).

Technical innovations have been developed to increase agricultural productivity in semi-arid regions with poor soils, yet these innovations are of little use if farmers do not adopt and adapt them to suit the needs of their own agro-ecosystem and cultural setting. Adoption of introduced innovations is unsustainable when farmers cease to use the innovations once extension initiatives have ended.

To be sustainable on a long term basis, research and extension initiatives must incorporate an understanding of the socio-economic and biophysical preconditions necessary for successful innovation adoption and dissemination. To date, these preconditions are not well defined in sub-Saharan Africa. Participatory research methods that facilitate farmer-led agricultural experiments may foster innovation adoption processes, while at the same time allowing the researchers to build an understanding of biophysical and socio-economic conditions within the target community.

1.2 Hypothesis

The hypothesis behind this study is that garden-scale water balances & irrigation requirements can be determined through participatory research. In addition, small scale farmers will be more likely to adopt a water use innovation if they are involved in the development and testing of that innovation. An understanding of socio-economic and biophysical conditions required for adoption and dissemination of innovations can be built through participatory research and innovation development.

1.3 Project Aim and Objectives

This project falls under the greater Smallholder System Innovations in Integrated Watershed Management program (SSI). It was intended to address SSI aims included in SSI Project 1a - *Adaptive development of water system innovations: assessment of socio-economic conditions for sustainable adoption at farm level,* and SSI Project 3 -

Building resilience of the eco-hydrological landscape: Biophysical and socio-economic analyses of agricultural innovations.

The specific aim of this research was to assess socio-economic conditions required for adoption and dissemination of innovations in a subsistence farming community while fostering farmers' problem solving abilities (and thereby adaptive management capacity) and investigating the biophysical aspects of garden scale water use innovations. To meet this aim, the primary objective was to facilitate farmer-led garden experiments using Participatory Learning and Action (PLA) research methods within the South African subsistence farming community of Potshini,. This PLA experimentation process created a venue for implementing the additional objective of determining soil moisture characteristics associated with different garden bed design innovations, while documenting the socio-economic and biophysical conditions that drive innovation adoption, adaptation and dissemination.

1.4 Main Research Questions and Thesis Organization

Overarching questions addressed during this project include:

a) What are the biophysical conditions and socio-economic processes that influence the adoption & dissemination of agricultural innovations in Potshini?

b) How do soil management innovations (including trench beds) impact moisture availability in the root zone?

c) How do water application innovations (including drip-kits and run-on ditches) impact moisture availability in the root zone?

The format of this thesis includes a literature review and discussion of research methodology, two publishable research articles, and a final discussion followed by appendices. All data and graphs are presented in appendices. One article focuses on socio-economic aspects of innovation adoption, while the other emphasizes soil water characteristics and moisture availability. Some overlap between the two articles exists as they are intended to be submitted to different journal publications.

2. SOCIO-ECONOMIC AND BIOPHYSICAL CONTEXT LITURATURE REVIEW

The study was focused on homestead gardening practices in Potshini, a subsistence farming community located in the Bergville district of the KwaZulu-Natal Province of South Africa. A number of agricultural innovations have been introduced in Potshini in an effort to improve resilience and livelihoods within the community, primarily though the SSI and Landcare projects discussed in Chapter Two of this thesis. Innovations have been adopted with varying degrees of success including rainwater harvesting tanks, homestead gardening practices, conservation tillage, liming, pest and weed control, multi-cropping and grazing management. Sustainable adoption, adaptation and dissemination of such innovations are linked to a variety of socio-economic and biophysical factors that influence decisions made by farmers, as discussed in the following sections.

2.1 Sustainability and its Connection to Resilience & Livelihoods

To understand why an innovation may or may not be adopted in a community, it is important to evaluate the biophysical and socio-economic factors that influence sustainability of agricultural innovations. This section presents a definition of sustainability, resilience and livelihoods, and explores the factors they are influenced by.

Sustainability has been defined in a variety of ways. The differences are primarily due to the fact that sustainability is relative to the people and the ecosystem under consideration. A working definition of sustainability must include the context as well as the spatial and temporal scales (Brown *et al.,* 1987).

Ekins (1995; p. 186) defined sustainability quite simply as 'the capacity to continue into the future indefinitely'. Chambers (1997; p. 11) expanded on this by stating that 'sustainability means that long-term perspectives should apply to all policies and actions, with sustainable livelihoods as objectives for present and future generations'. Additionally, the goal of sustainable land management is to provide environmental, social and economic opportunities for the benefit of present as well as future generations, while maintaining and enhancing the quality of ecologic resources, including air, water and soil (Smyth and Dumanski, 1993). As such, sustainability encompasses a complex array of interconnected environmental and social elements (Steiner *et al.*, 2000).

In the Potshini catchment, sustainability is dependent on the management of agricultural systems. Sustainability of agro-ecosystems depends on the maintenance of social, economic and biophysical components that make up the system (Belcher *et al.*, 2004). Pretty (1995) presented a comprehensive set of conditions which describe sustainable agricultural systems:

- Incorporates natural processes such as nutrient cycling into the production processes.
- Reduces non-renewable inputs that may damage the environment and harm farmer's health. This also minimizes variable costs.
- Progresses towards a more socially-just form of agriculture.
- Makes increasing use of biological and genetic potential of plant and animal species.
- Increases the use of local knowledge and practices.
- Allows farmers and rural communities to become more self-reliant.
- Matches crop patterns with production potential and environmental constraints of climate and landscape.
- Facilitates profitable and efficient production using integrated farm management.
- Conserves soil, water, energy and biological resources.

This set of diverse socio-economic and biophysical conditions illustrates the need for an integrated approach to resource management and agricultural system development. Pretty (1995) further suggests that for agriculture to be sustainable, local groups and institutions must work together with external institutions to initiate and maintain conservation technologies.

Five common themes have emerged from sustainability studies and have been identified as the 'pillars of sustainability' (Dumanski, 1994; Hurni, 2000). For a system to be sustainable, it must allow future generations to meet their needs while providing the following ‘pillars’ for the present generation: protection of ecology, acceptability to society, economically productive, economically viable, and effective in reducing risk. These five pillars have been adapted by Walker (2005), to suit the context of semi-arid sub-Saharan African agricultural intensification as follows:

- Resilience of agro-ecosystems,
- Social concerns and reducing risk,
- Economic production and viability, and
- Political constraints.

A closer evaluation of dynamics of these components is presented in the following sections (2.1.1 to 2.1.4).

2.1.1 Resilience of agro-ecosystems

The ecological resilience of a system is defined as its ability to cope with randomness, extreme events and shocks (such as droughts or floods) through a capacity to absorb shocks while maintaining function (Holling, 1986). Resilience applies to integrated social and ecological systems by (1) the amount of disturbance a system can absorb while remaining in the same state, (2) the degree to which the system is capable of self-organization, and (3) the degree to which the system can increase capacity for adaptation and learning (Carpenter *et al.*, 2001). A resilient system is not only able to absorb shocks but also has the potential to benefit from change through the adaptive process of creating opportunity for development, innovation and novelty. When a system loses its resilience it becomes vulnerable to disasters triggered by shocks that cannot be absorbed. A system in the vulnerable state can be devastated even by small changes.

Building and maintaining resilience in agro-ecosystems depends on diversity within the system, as well as knowledge about system dynamics and the implications these dynamics have for income and output. The capacity of an agro-ecosystem, which is both an ecological and an economic system, to function over a range of environmental and social conditions depends on the diversity of both financial and natural assets within the system. Biodiversity facilitates ecological functioning and hence the production of valuable ecosystem services by building in functional redundancy. Trade-offs between resilience and productivity are common, and the most resilient systems in the long term may not be the most productive in the short term (Perrings, 2006). Resilience building resource management must ensure sustainability of the social and ecological system over the long term. Such management will improve the ability of a system to generate economic assets as well as sustainable ecosystem services that benefit human livelihoods (Rockström, 2003).

2.1.2 Social concerns and reducing risk

Agriculture is inherently a risky enterprise and farmers' perceptions of risks are associated with both biophysical and socio-economic factors. The biophysical aspects of these risks are examined in Section 2.2, Chapter One of this thesis. Socio-economic concerns strongly influence the adoption and dissemination of agricultural innovations that are intended to reduce risk. In the case of subsistence farming, the livelihoods of farmers (particularly as related to food security and income levels) depend on production stability, hence perceptions of risk play a major role in making decisions about farming practices (Walker, 2005; Jones and Thornton, 2003). If the costs of innovation implementation are perceived to be greater than the expected benefits, farmers are not likely to adopt or even try a new practice.

Perceptions of risk and associated costs are formed by a complex set of cultural and economic processes. To develop an understanding of these processes, it is important to consider cultural underpinnings, such as the role of women in agriculture as well as livelihood priorities and strategies within a community. Other risk-related factors that influence farmers' decisions about innovation adoption include required inputs, production system options, marketing, productivity expectations, off-farm activities and responsibilities (Ngigi *et al.*, 2005).

2.1.2.1 Potential Risk Reduction through Gardening

A recent study by Faber (2005) in rural KwaZulu-Natal showed that nutrient intake for rural South African infants was inadequate, especially for calcium, iron and zinc. To address such nutritional deficiencies, development organizations have initiated vegetable garden projects throughout Sub-Saharan Africa. Garden initiatives have also been aimed at improving diet diversity and income for target populations. However, success of these efforts has been variable, depending greatly on the socio-economic and biophysical context in which they were introduced (Frankenberger *et al.*, 1989). Two case studies, one based in Mauritania and one in Lesotho, illustrate the influence of socio-economic and biophysical context on the success of gardening projects, as discussed in the following paragraphs.

Efforts to promote commercial vegetable production in Mauritania during the 1970s and 1980s were largely unsuccessful. The major constraints identified included climate, access to inputs, access to knowledge about sound gardening practices through extension programmes, marketing, limited knowledge of techniques for conservation and transformation of vegetables (Stone, Perquin and Hamidou 1987). Market oriented vegetable garden interventions in this type of setting are more likely to be successful when infrastructure for obtaining inputs and marketing outlets exist. Without such resources, gardens may be more sustainable at a subsistence level than at a commercial level (Frankenberger *et al*., 1989).

In Lesotho, a study conducted by Saenz de Tejada (1989) showed that farmers who had individual homestead gardens had more varied diets and generally higher consumption of most food items than those participating in a cooperative garden association. This was attributed to an increased availability and consumption of leafy vegetables that might be replacing foods previously consumed by association members. Additionally, it was noted that cash income received by association members may be too small to offset necessary non-food purchases. Increased cash income was found to lead to consumption of foods that are associated with high social status, but that are less nutritious than previously consumed foods, such as wild greens that are good sources of protein, calcium, iron, phosphorous and vitamin A.

A development study by Schmidt and Vorster (1995) indicated that participation in communal gardens does not guarantee better nutritional status for household members. However, they did find that growing vegetables was beneficial because households with gardens spent food money on items such as fat and oil rather than purchasing vegetables. Research based in a rural village in Bophuthatswana implied that for vegetable gardens to provide enough vegetables for all household requirements, a large garden plot would be needed (Scmidt, 1993, quoted by Brutsch, 1994). This raised the (unanswered) question of whether the average rural household has the labour resources, land and water to produce required quantities. This study also emphasized that vegetable gardens do not directly address the insufficient intake of protein and energy that tends to be a more serious nutritional problem than vitamins and minerals in developing areas of Southern Africa. In order to contribute significantly to energy and protein intake, gardens would need to produce crops such as potatoes or sweet potatoes on a large scale.

Research on the contribution of homestead and communal gardening to livelihoods in SSA is limited. The studies that have been completed indicate that gardens may or may not improve nutritional or economic status, thereby reducing risk, of rural people. The potential for risk reduction through gardening depends on the socio-economic and biophysical setting.

2.1.3 Economic production and viability

Water availability is often cited as the critical constraint to crop growth in tropical semi-arid SSA areas, such as the Sahel (Lal, 1991). However, the amount of seasonal or annual rainfall is often less limiting than the irregular occurrence of rainfall events (Sivakumar and Wallace, 1991). Additionally, soil nutrients can have as much or more influence on the growth of crops than water in semi-arid environments (Fox and Rockström, 2003). It is therefore necessary to assess the condition and probable fluctuations of each of these elements when determining whether an agricultural innovation will be sustainable and economically viable in a given location.

Management practices of the more productive farming systems in semi-arid regions often include the use of improved crop rotation, optimal sowing dates, crop density, weed control, pest and disease control, fertility management, suitable crop varieties, supplemental irrigation and water conservation. Appropriate crop varieties should have a strong response to limited water applications and have some drought resistance (Oweis and Hachum, 2006).

Although land and water management play a critical role in agricultural viability, farm profitability is not necessarily increased by increasing crop production per unit of land or unit of water. This is because crop yield does not have a linear relationship with production inputs, especially in terms of water and its interactions with other input factors (Oweis and Hachum, 2006). The crop output per cubic metre of water is termed water productivity (WP) and is often referred to as “crop per drop”. Agricultural innovations that increase WP may require additional monetary or labour inputs than traditional practices. For example, reducing water applications or using minimum tillage may require more weeding or the purchase of herbicides, and conversion to drip irrigation can conserve water, but requires capital investment. These types of trade-offs may not be cost effective in the eyes of the farmer. For these reasons, it is more useful to aim for optimizing WP, rather than maximizing WP. Efforts that effectively optimize WP will account for the social as well as the economic values of all system inputs and outputs. Although it is difficult to measure net social returns resulting from implementation of an innovation, the cost involved in increasing WP and the reality that not all increases in WP are desirable, are important factors to keep in mind when making judgements about practices that improve WP (Barker *et al.,* 2003).

In addition to overall WP and crop production, economic viability of farming depends on the capacity of farmers to access viable markets (Rijsberman and Manning, 2006). This access is tied to multiple socio-economic factors, such as the availability of transport and competition from large scale farmers.

2.1.4 Political constraints

With the development of South Africa's National Water Act, the country's national government has shown substantial commitment to using an Integrated Water Resource Management approach to allocating water and protecting the ecosystems that support subsistence farmers and other users (DWAF, 1996). In theory, small-scale farmers should be able to participate in water policy decision making and implementation through Water User Associations. These associations are usually in charge of management of water use by farmers, as well as building, operation and maintenance of waterworks. They are not entitled to modify the distribution of water licenses, which is currently performed by the DWAF and will eventually be delegated to the Catchment Management Agencies. While WUAs do have some impact in the process of policy development and implementation, they do not demographically represent the population of domestic and agricultural water users. Locally, it is the Irrigation Boards (formerly white-only organizations) that have become Water User Associations in South Africa. They are meant to incorporate all water users, whether they have a formal water entitlement or not. However, the process of inclusion has not been equitable. Only one in six Irrigation Boards had been converted into WUAs by 2003 and the involvement of small-scale users in the accepted WUAs is not obvious. Commercial farmers remain in charge of proposing how the WUA will function. They have opened the Irrigation Boards to small-scale users only if these users' activities have an impact on their own activities, or if the small-scale users are required to pay fees to the WUA. The lack of internal organization of small-scale users such as rural communities and farm workers has helped to maintain their lack of inclusion in the WUAs. This lack of organization is exacerbated by the fact that many of these users are poorly educated, have little or no access to computers, and may not be literate. In two case studies conducted by the International Water Management Institute, small-scale farmers had rights to more water than they were allocated, but they did not receive the information needed to claim additional water. It was also found that large-scale farmers remained in control of all decision making at the WUA level (Faysse, 2004).

2.2 Water System Dynamics in Sub-Saharan Africa

A primary means of poverty reduction for rural SSA populations is to increase local food production through improved productivity of arable land and available water resources (Rockström, 2000). To identify agricultural innovations that may enhance the ability of smallholder farmers to produce vegetables on a sustainable level, it is necessary to understand local, biophysical influences on food production, including plant and soil properties as well as water availability and the local water balance.

2.2.1 Water balance parameters

There are several factors that influence the amount of water required for supplemental irrigation of vegetable gardens in Potshini. To identify and understand the influence of these factors it is necessary to evaluate the local water balance. Water balances account for all inputs and outflows of water in a system. Crop fields comprise six water flows: precipitation, runoff, evaporation from the soil, drainage, transpiration from plant leaves, and irrigation (Gerbens-Leenes and Nonhebel, 2004), as displayed in Figure 1.1.

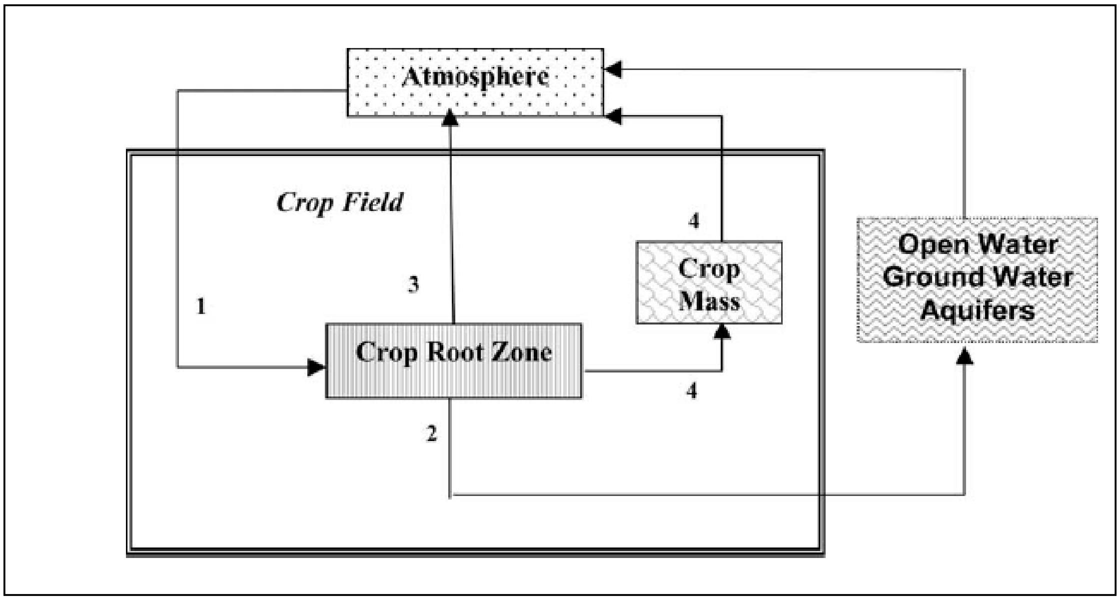

Figure 1.1: Simplified diagram of water flow and the two water stores (crop mass and crop root zone) in a crop field (Gerbens-Leenes and Nonhebel, 2004). Flow 1 = total inflow from precipitation, irrigation and runon. Flow 2 = horizontal outflow of water to rivers and aquifers, and vertical flow leaving the root zone to lower layers (groundwater and eventually open water). Flow 3 = water evaporated from soil. Flow 4 = water flow that passes through crops as transpiration.

While it is important to measure or estimate all hydrologic parameters to determine an accurate water balance, including surface and atmospheric water movements, special focus must be given to determining changes in soil moisture within the system. Collection of soil moisture data is not as straight forward as recording water volumes in rain gauges or from runoff plots, however, it is an important variable in both biologic and hydrologic processes. It is a controlling variable in energy and water exchanges between the atmosphere and land surfaces as it acts as a limit to transpiration and evaporation flows. It thus controls the partitioning of incoming solar radiation and long wave radiation into outgoing long wave radiation and ground, latent and sensible heat fluxes. Additionally, antecedent soil moisture determines partitioning of precipitation into infiltration, runoff and surface storage (Pachepsky, *et al*., 2003). Hydraulic conductivity of garden soils will have a significant impact on the amount of water runoff, storage, drainage, abstraction and evaporation from gardens. Measurements of hydraulic conductivity, as well as direct measurements of water content, soil water tension and daily rainfall were collected during this study in an attempt to build an understanding of garden scale water balances at in Potshini. A discussion of data collection methodology is presented in Section 3, Chapter One of this thesis.

2.2.2 Non-productive water flows

Large, non-productive flows in on-farm water balances have resulted in low crop yields in sub-Saharan Africa. Non-productive water losses include runoff, deep percolation (drainage), and direct soil evaporation (Rockström et al., 2004). Low crop production due to water scarcity can be largely attributed to sub-optimal partitioning of rainfall, resulting in such non-productive water losses. Soil evaporation is believed to account for 30% to over 50% of rainfall in SSA, while productive flow in the form of transpiration accounts for only 15 to 30% (Rockström, 2000). A breakdown of typical rainfall partitioning in SSA can be seen in Figure 1.2.

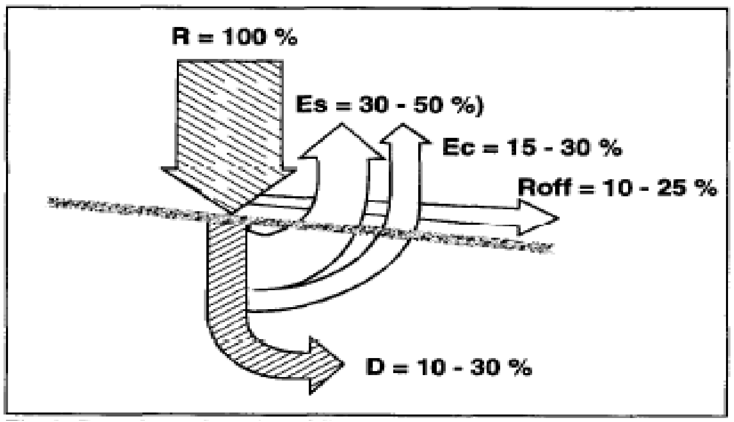

Figure 1.2: Rainfall partitioning in SSA. R = seasonal rainfall, Es = Evaporation (from soil and interception), Ec = transpiration, Roff = surface runoff, and D = drainage (Rockström, 2000).

Runoff response in SSA is generally quite rapid and if not captured, the water flows to sinks as a flood wave, from where it is usually not economical to recover for productive use (Hatibu *et al.,* 2000).

2.2.3 Risk reduction through water system innovations

Significant non-productive water flows combined with dry spells caused by temporal and spatial rainfall variability create high seasonal risk of soil water scarcity in terms of crop production water requirements. This threatens resilience of communities dependent on agriculture for their livelihoods (Enfors and Gordon, 2007). A number of water system innovations (WSIs) and other forms of intervention may be used to alleviate the negative effects of dry spells and poor water partitioning. Rockström (2003) summarized the possible interventions for dealing with water scarcity and soil deficiencies, as shown in Table 1.1.

Table 1.1: Biophysical conditions affecting crop yields and social resilience as well as possible relief interventions (shown in *italics*) and resilience-building options (After Rockström, 2003)

Biophysical Condition	Effects of Biophysical Condition	Impact	Resilience-Building Options & *Relief Interventions*
Poorly distributed rainfall	Meteorological dry spell • Rainfall deficit of 2-5 week periods during crop growth	Yield reduction	• Water harvesting
	Meteorological droughts • Seasonal rainfall below minimum seasonal plant water requirements	Complete crop failure	• Water harvesting • *Virtual water imports* • *Relief food* • *Cereal banks*
Poor on-farm rainfall partitioning	Agricultural dry spells • Poor rainwater partitioning • Low plant water availability	Yield reduction OR complete crop failure	• Soil and water conservation
	Agricultural droughts • Poor rainfall partitioning leading to seasonal moisture deficit to produce a harvest	Complete crop failure	• Water harvesting
Unfavourable soil properties and deficiencies	Low plant water uptake capacity • Low soil fertility • Low water holding capacity • Weak roots, poorly developed canopy	Yield reduction	• Soil fertility and crop management

Relief interventions such as cereal banks and virtual water imports alleviate imminent threats of starvation in some circumstances, but they do not build resilience through long-term, sustainable solutions to inadequate crop yields. Long term risk reduction can only be achieved through ecological and social resilience building.

A number of studies have shown that the gap between what is presently produced on rain-fed farms in semi-arid regions and what could be produced is not explained by biophysical conditions, but rather by sub-optimal farm management (Rockström, 2000). Land and water management can be greatly improved by the use of water system innovations. Various WSIs have been developed to increase system resilience through lessening the impact of dry spells on crop production in semi-arid environments, including:

- In-situ water conservation techniques (to maximize rainfall infiltration and water holding capacities) - conservation tillage, furrows, contour strips, terracing, crop residue management, intercropping, cover cropping, etc.,
- Flood irrigation - runoff and stream flow diversion, groundwater recharge systems, spate irrigation, etc., and
- Storage for supplemental irrigation – subsurface dams, surface dams, tanks, etc. (Rockström, 2000 and Rockström, 2003).

Effective mitigation of dry spells also depends on the socio-economic acceptability of the innovation, which can be related to labour input, cultural beliefs or other factors. Water harvesting innovations used to mitigate different types of hydro-climatic hazards as well as the socio-economic potential of each are presented in Figure 1.3.

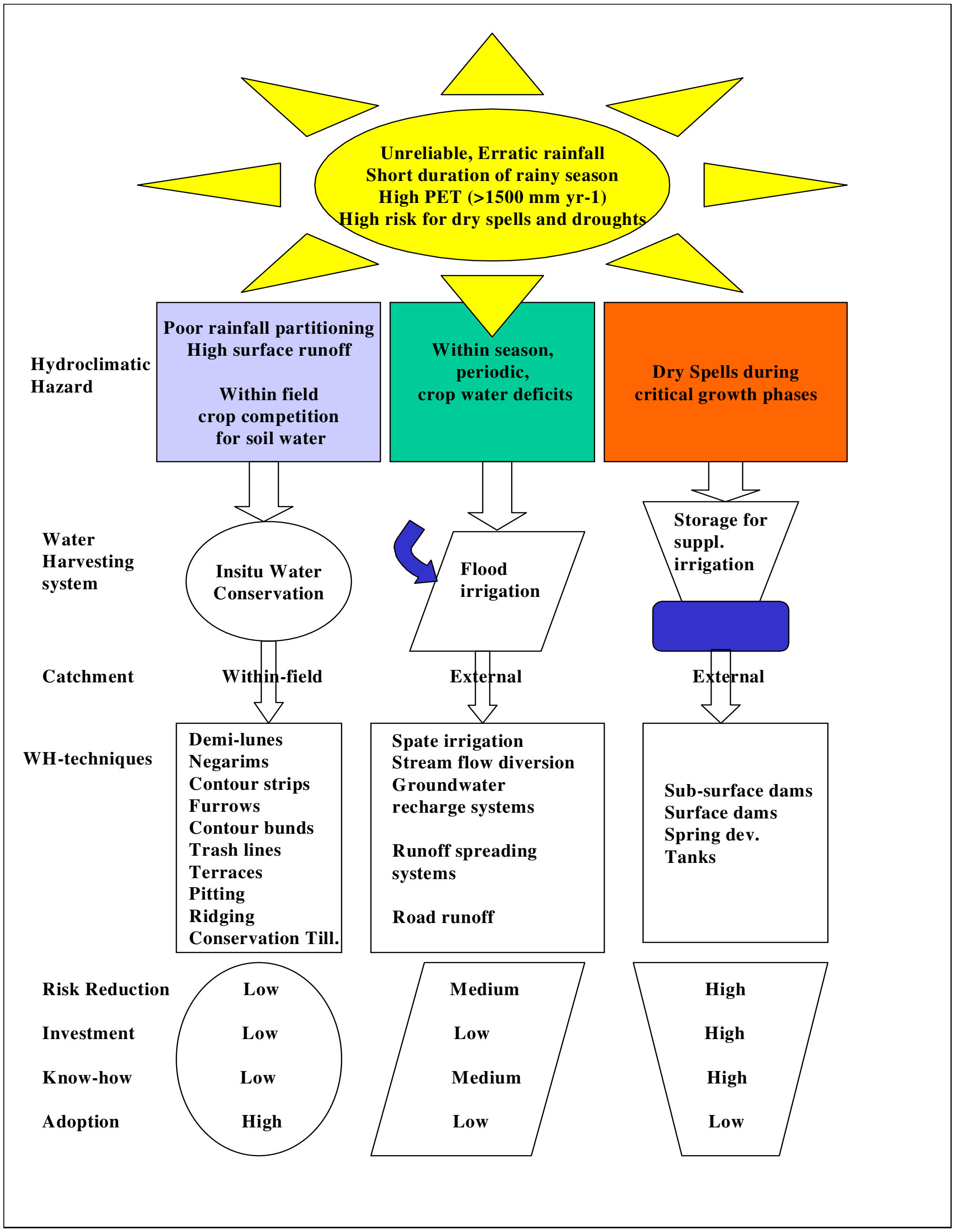

Figure 1.3: Flow chart showing water harvesting methods used to mitigate the effects of various hydro-climatic hazards, and the socio-economic implications of their use rural communities (Rockström, 2000).

The overall potential for reducing risk through development of WSIs like small farm ponds and supplemental irrigation depends on a number of site specific socio-economic and biophysical factors. These factors may include population pressure, formal and informal institutions, land tenure, economic environment, social structures, land degradation and farming system practices (Ngigi, 2003).

2.3 Biophysical and Socio-Economic Dynamics of the Project Area

A biophysical description of the Potshini sub-catchment is presented in Chapter Three of this thesis. Some of the socio-economic dynamics of the project area are presented in Chapter 2 of this thesis, and additional socio-economic detail is provided in this section.

An interview-based study conducted by Henriksson (2004) revealed that in the late 1970's most of the current houses in Potshini were not present. There were around 200 houses in the village in the early 1980s, when many people started to move into the area. The migrants came primarily from white commercial farms around the town of Winterton. Others came from communities 60 to 70 km away. People were drawn to the area because they were able to have livestock and cultivate their own crops in Potshini. In 2000 the main road in Potshini was upgraded, allowing more people to have jobs in nearby towns because of the available taxi service. The same year campaigns for local council elections resulted in friction amongst community members and a partial breakdown of community solidarity.

Livestock are moved to the veld above the village at a date set by the chief so that planting can begin. The harvesting date is also set by the chief each year and is usually between the first or second week in June. The livelihoods of Potshini community members are based upon a combination of income sources and ecosystem goods.

Ecosystem goods and services utilized in Potshini are listed in Table 1.2. Participatory Rural Appraisal techniques (such as group interviews and constructing seasonal maps) suggested that community members rely more on income sources to supplement food grown for subsistence than ecosystem goods. Sharing through social networks is an important survival strategy in times of limited food supplies, but purchase of mealie meal (maize) proved to be the dominant strategy in compensating for poor crop yields Henriksson, 2004).

Table 1.2: Description of ecosystem goods and services used by the Potshini community (after Henriksson, 2004)

Water	Water from hand pumps is used for drinking and washing. Several natural springs provide drinking water for humans and livestock. Washing requires significant quantities of water and during Easter and Christmas holidays more water than usual is used for this purpose. Brick making also requires significant amounts of water, especially from May to July. Making plaster for houses also requires water during April and December.
Firewood	Used as a fuel source for cooking and heating houses during winter months. Two main types of wood used are the indigenous Umkhambi and the invasive Wattle. Wood is also a building material.
Straw	Used for making mats, cups for traditional beer and cutting boards.
Grass	Thatch grass is used for making roofs and is cut in July and August. Unkomfe (cut April-June) and Umsingizane (cut around June) are used to make ropes. Uhashu (cut July to November) is used to make brooms.
Fodder	Several types of grass are used as fodder for livestock.
Stone	Stone and rocks are used for building roads
Wild animals	Rats, birds, porcupine, buck, hare, snakes and grasshoppers are hunted or collected for eating. Hunting was more common in times past and is not practiced much today.
Wild herbs	There are several wild herbs, including mushrooms, that can be eaten during different seasons, especially during November to January. Mainly only elder women eat them.
Medicine herbs	Several species are used for medicinal purposes.
Mud	Several types of mud are used for making bricks for building houses during May to July. Mud is also used to make plaster from April to December.
Manure	Used as a burning material for cooking and heating houses. It is also used for plastering floors and as a fertilizer.

3. RESEARCH METHODOLOGY LITURATURE REVIEW AND DISCUSSION

To evaluate the pre-conditions necessary for sustainable adoption, adaptation and dissemination of innovations, it is necessary to gain an understanding of the aspects that influence farmers' decision-making processes. This requires working directly with farmers and was therefore implemented using participatory learning and action techniques. Other methodologies employed for building an understanding of garden-scale soil water availability included data collection with Wetting Front Detectors, Watermark® sensors, a Capacitance Probe, soil characterization tests and rain gauges.

3.1 Participatory Learning and Action Research Techniques

Participatory Learning and Action (PLA) research is one of many approaches to action research. It is generally accepted that all forms of action research involve inquiry that is done *with* or *by* stakeholders in a community or organization, but never *to* or *on* them (Herr and Anderson, 2005). Action research has also been defined as "learning by doing", wherein a group of people identify a problem, try something to resolve the problem, evaluate the success of their action and, if not satisfied, revise the plan of action and try again (O'Brien, 2001). The cyclical nature of action research is often summarized with the following steps: Plan - Act - Observe - Reflect, as expressed in figure 1.4.

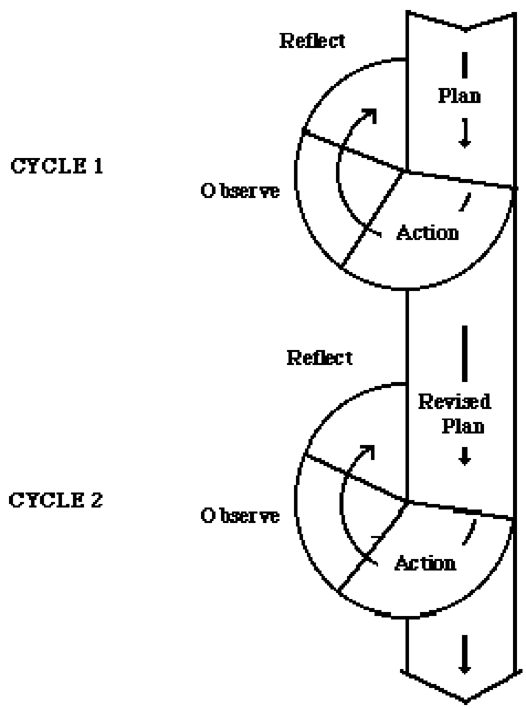

Figure 1.4: Simplified Action Research Model (OBrien, 2001)

The four Action Research steps were utilised with and by farmers who participated in Farmer Learning Workshops as well as facilitated experimentation during the research conducted for this thesis. The steps were used specifically to help farmers make decisions about the value of various gardening innovations that were discussed during the workshops. For the purpose of this project, innovations are defined as a technology or practice (or modification thereof) that is new to an individual or community. In

Potshini, many innovations were introduced through Farmer Learning Workshops, such as trench beds, rain gauges and mulch. Additionally, farmers were encouraged to try their own innovations in their gardens by modifying introduced innovations when needed or experimenting with their own ideas in the garden.

Participatory assessments of livelihood strategies are fundamental for understanding how such strategies rely on natural resources and for determining the adoptability of a resource management innovation (Carney, 1998; Pound *et al*. 2003). The primary aim of this study has been to gain a better understanding of the preconditions that determine whether an agricultural innovation can and will be adopted by subsistence farmers in the Potshini catchment. The platform for accomplishing this goal, i.e. facilitation of farmer-led garden experiments, is also intended to build capacity for adaptive management within the community through developing problem-based experimentation skills. This type of platform was chosen because it provides a means for working directly with farmers on a continual basis for a period of time. This allowed the researcher to build relationships with the farmers and to implement several PLA research techniques that lead to a better understanding of why these farmers choose certain agricultural practices over others. PLA methods played a primary role throughout this research because it has been shown that small-scale farming and soil conservation projects in Africa are generally more successful when farmers are treated as part of the solution rather than part of the problem (Critchley, 1991). Indigenous knowledge has been shown to contribute valuable insight into the physical suitability of an area for agricultural use and development (Bocco, 1991; Palwuk *et al*., 1992; Sandor and Furbee, 1996; WinklerPrins, 1999). Furthermore, there is evidence that technology transfer has often had negative effects on smallholder agricultural systems when indigenous knowledge of soils and other environmental conditions were not considered (Palwuk *et al*., 1992). It is therefore critical that local farmers be involved in the process of agricultural innovation development.

Participatory research methods (such as PLA) for identification of ecosystem services and innovation evaluations have become more common and offer a methodical means for involving farmers in the research and development process (Bellon, 2000). It is important however, to recognize the potential for misinterpretation of information gathered through participatory research (Bentley, 1994).

Extractive techniques, such as questionnaires and surveys, which allow large numbers of surveys to be conducted and provide numerical information for statistical analyses, have commonly been used by social scientists. Unfortunately these techniques do not reveal local complexities because contextual grounds for understanding are removed and cultural divisions which can affect responses are not acknowledged (Dalal-Clayton and Bass, 2002). Alternatives to such extractive techniques have been developed over the past few decades and have gained considerable credibility. These participatory approaches to gathering information include AEA (agro-ecosystem analysis), RRA (rapid rural appraisal), DRR (diagnositco rural rapido) and MARP (methode acceleré de recherché participative), which are oriented towards problem diagnosis. Others focus on community empowerment, such as PAR (participatory action research) and TFD (theatre for development), while some are meant to facilitate on-farm research like FPR (farmer participatory research). Some methods have been designed to suit specific types of development, such as PALM (participatory analysis and learning methods), which is geared toward watershed development (Dalal-Clayton and Bass, 2002). The wide array of approaches is actually a sign of strength in the field of participatory research, because it shows that each method has been tailored to suit a specific context, rather than attempting to bend the context to suit the method. However, these approaches have certain principals in common, as summarized below.

Principals of Participatory Learning and Action:

- *Cumulative learning by all participants.* Interaction is fundamental and visual emphasis enables everyone to take part on an equal basis.
- *Seek diversity* over attempting to characterize complexity in terms of averages. There are several possible descriptions of any one activity.
- *Group learning.* The complexity of a situation will only be revealed through group interaction and enquiry with a mix of investigators from different disciplines, including outside professionals in local people.
- *Context specific.* Approaches are adapted to suit each new set of conditions and participants.
- *Facilitating role of experts.* The aim is to develop changes that are regarded as improvements by stakeholders. The role of the "expert" is to help people carry out their own study and make their own plans.

- *Sustained action*. This includes the strengthening of local institutions, which increases the capacity of people to initiate action on their own (Petty *et al*., 1995).

Participatory learning and action (PLA) reaches beyond the idea of teaching and technology transfer, which implies an information transfer from those who know to those who do not know, to a method of investigation and analysis by local people. These locals are then able to share what they have discovered with outside stakeholders such as researchers and government agents. PLA methods, such as matrix scoring and ranking, analysis of air photos, participatory mapping, flow and linkage diagrams, and seasonal analyses are not only tools for local farmers to provide information to outsiders, they also provide methods for farmers to conduct their own investigations, to gain valuable insight about their own situation (Chambers, 1992).

The techniques of PLA can be divided into four types: group and team interaction, sampling, dialogue and visualization / drawing. The emphasis on pictorial techniques has proven to be one of the great strengths of PLA, because it allows everyone who can see to contribute actively to a discussion or analysis. Non-literates are not excluded from the process when creating and discussing a map or diagram. Everyone present, both locals and outsiders, can see, point to, debate and refine the picture (Dalal-Clayton and Bass, 2002). Bass *et al*. (1995) summarized the various techniques, as shown in Table 1.3.

Table 1.3: Summary of Participatory Learning and Action research techniques, after Bass *et al.* (1995)

Group & Team Interaction	**Sampling**	**Dialogue**	**Visualization & Drawing**
• Team contacts • Team reviews and discussions • Interview guides and checklists • Rapid report writing •Energizers/activators • Work sharing (taking part in local activities) • Villager and shared presentations • Process notes and personal diaries	• Transect walks • Wealth ranking and well-being ranking • Social maps • Interview maps	• Semi-structured interviews • Direct observation • Focus groups • Key informants • Ethnohistories and biographies • Oral histories • Local stories, portraits and case studies	• Mapping and modelling • Social maps and wealth ranking • Transects • Mobility maps • Seasonal calendars • Daily routines and activity profiles • Historical profiles • Trend analyses and time lines • Preference or pairwise ranking • Matrix scoring • Venn diagrams • Network diagrams • Flow diagrams • Pie charts

Despite the growing acceptance and use of Participatory Learning and Action techniques, "top-down" strategies of development persist for various reasons. One is that it is difficult to achieve effective participation in a single exercise, which means that a significant amount of time is required for participatory processes to be effective. Another is that it is difficult to ensure continued commitment and engagement from local stakeholders when past involvement in participatory approaches has been mainly superficial and their opinions have not truly been taken into account (Dalal-Clayton and Bass, 2002).

3.2 Estimating Water Availability

Various instruments were placed in six farmers' gardens in Potshini. These tools included rain gauges, Wetting Front Detectors, nested Watermark® sensors, and Capacitance Probe tubes, the latter three of which are discussed in the following paragraphs. Information from these tools was supplemented with soil lab analyses and in-field soil hydraulic characterization tests. Data provided by these tools has been used to estimate the changes in water availability in the root zone over one summer growing season, as discussed in Chapter Three of this thesis. Through modelling and further data analyses this information could also be used to estimate the local water balance and the amount of water that must be harvested to sustain a household garden in summer months. With further participatory field investigations it could also provide farmers with a means for understanding the optimal times to irrigate and how much water should be applied during irrigation events.

Wetting Front Detectors (WFDs) are a relatively new technology that is designed to be simple to operate and understood by farmers. They are meant to bridge the gap between science and the practice of irrigation scheduling and are based on the assumption that farmers want to replenish water in the root zone after it has been used by the plants (Stirzaker *et al.*, 2004). The WFDs provide a visual signal to inform farmers when the "wetting front" has reached a certain depth. Farmers in Potshini recorded the time they started irrigating, the amount of water applied, and the time WFDs were activated. This information provided insight into water content after wetting events as well as the velocity of water movement within the soil and can be directly compared to water content and tension measurements collected in the same locations.

Soil water potential can be measured by tensiometers or Watermark® sensors. These instruments each measure the water tension in the soil, which increases with decreasing water content. The advantage of Watermark® sensors is that they can accurately detect relatively high tensions (up to 200 centibars) though they are less sensitive and slower to respond in very wet conditions with low tensions. Tensiometers only work for soil water potentials up to about 80 centibars, so they may be off the scale much of the time in arid regions (Irrometer Co., 2006). Because of this, the Watermark® sensors are considered to be a better choice for research in the Potshini area.

Near surface changes in soil water content can be measured using a Capacitance Probe. It functions by sending a very high frequency (~GHz) electrical signal into the soil. The signal that is reflected is a function of soil water content (Wallace, 1996). Determination of travel time, t, of the signal pulse yields the velocity, V, during two way travel by the following equation, where L is the distance travelled one way (Topp *et al.*, 1996):

$$V = 2L/t \qquad (1.1)$$

A second equation can also be used to determine signal velocity (Topp *et al.*, 1996):

$$V = c(K_a)^{1/2} \qquad (1.2)$$

Where $c = 3 \times 10^8$ m/s (the propagation velocity of electrical signal in a vacuum), and K_a is the apparent dielectric constant of the soil being measured. By equating these two expressions for V, the apparent dielectric constant of the soil can be determined as follows:

$$K_a = (ct/2L)^2 \qquad (1.3)$$

The apparent dielectric constant depends on soil water content (θ) according to the following linear relationship (White *et al*., 1994; Hook and Livingston, 1996; and Ferre *et al*., 1996 as cited in Topp *et al*., 1996):

$$K_a = C_1\,\theta + C_2 \qquad (1.4)$$

Where C_1 and C_2 are constants that depend on the soil properties.

A TRIME® tube-access probe was used for the purposes of this research, as opposed to a conventional capacitance rod probe because it allows for water content profiling (by recording water content information from multiple depths) that was intended to complement Watermark® sensor data (recorded at 3 fixed depths). The drawback of the tube-access probe is that data are collected manually rather than in a steady stream of digital readings. Additionally, underestimation of water content can result when close contact between the access tube and surrounding soil is not achieved during installation of the tube, which resulted in unusable readings during the first six weeks of data acquisition for this study. Additionally, once the tubes were placed with proper soil contact, the probe itself was in need of physical repair after only 6 weeks of use, requiring several weeks of shipping and repair time (the limited data available is presented in Appendix A). As a result, Capacitance Probe data collected during this study was insufficient for technical analyses. Information from technical tools was supplemented with laboratory generated soil analyses (hydraulic conductivity and nutrient analyses) and in-field soil hydraulic characterizations (double ring and tension disc infiltrometer tests). Curves were fitted to hydraulic characterization data using the van Genuchten equation (van Genuchten, 1980) and used to strengthen interpretations of soil water tension data. Additional description of hydraulic characterizations and of the function of WFDs, WMSs and Capacitance Probes is provided in Chapter Three of this thesis.

REFERENCES

Barker, R, Dawe, D, and Inocencio, A. 2003. Economics of Water Productivity in Managing Water for Agriculture. In: ed. Kijne, JW, Barker, R, and Molden, D, *Water Productivity in Agriculture: Limits and Opportunities for Improvement,*Chaper 2, 19-35. CAB International, Wallingford, UK.

Bass, SMJ, Dalal-Clayton, DB and Pretty, J. 1995. Participation in Strategies for Sustainable Development', *Environmental Planning Issues*, no 7, International Institute for Environment and Development, London, UK.

Belcher, KW, Boehm, MM and Fulton, ME. 2004. Agroecosystem Sustainability: A System Simulation Model Approach. *Agricultural Systems* 79:225-241.

Bellon, MR. 2000. Participatory Research Methods for Technology Evaluation: A Manual for Scientists Working with Farmers. [Internet]. International Maize and Wheat Improvement Center (CIMMYT), Mexico. Available from: http://www.cimmyt.org/Research/Economics/map/research_tools/manual/PRM_Bellon.htm. [Accessed 15 August 2006].

Bentley, JW. 1994. Facts, fantasies, and failures of farmer participatory research. *Agriculture and Human Values* 11(1994):140–150.

Bocco, G. 1991. Traditional knowledge for soil conservation in central Mexico. *Journal of Soil & Water Conservation* 46 (5): 346-348.

Brown, B.J., Hanson, M.E., Liverman, D.M., Merideth Jr., R.W. 1987. Global Sustainability: Towards Definition. *Environmental Management* 11:713-719.

Brutsch, MO. 1994. Gardening for Better Nutrition: Estimating the size of a Home Vegetable Garden in Southern Africa that will Provide the "Reasonable" Vegetable Needs of an "Average" Family. Department of Agronomy, University of Fort Hare. Paper presented at the Fourth Annual Congress of the Southern African Society for Horticultural Sciences, Nelspruit. 25-27 January 1994.

Carney, D. 1998. *Sustainable Rural Livelihoods: What Contribution Can We Make*? Sustainable Livelihoods Support Office, Department for International Development, London.

Carpenter, SR, Cole, JJ, Hodgson, JR, Kitchell, JF, Pace, ML, Bade, D, Cottingham, KL, Essington, TE, Houser, JN, and Schindler, DE. 2001. Trophic cascades, nutrients, and lake productivity: whole-lake experiments. *Ecol. Monogr.* 71:163–186.

Chambers, R. 1992. Methods for Analysis by Farmers: The Professional Challenge, paper for the *12th Annual Symposium of Association for Farming Systems Research and Extension*, Michigan State University, Ann Arbor, Michigan

Chambers, R. 1997. Whose Reality Counts? Putting the First Last. Intermediate Technology Publications, London, UK.

Critchley, W. 1991. *Looking After Our Land: New Approaches to Soil and Water Conservation in Dryland Africa*. Oxfam Publications, Oxford, UK.

Dalal-Clayton, B; and Bass, S. 2002. Sustainable Development Strategies: A Resource Book. [Internet]. The Institute for Environment and Development. Earthscan Publications Ltd. Sterling, VA, USA. Available from: http://www.nssd.net/res_book.html. [Accessed 11 September 2006].

Dumanski, J. 1994. Proceedings of the International Workshop on Sustainable Land Management for the 21st Century, Vol. 1: Workshop Summary. The Organising Committee, Agricultural Institute of Canada, Ottawa.

DWAF. 1996. White Paper on a National Water Policy for South Africa. [Internet]. Department of Water Affairs and Forestry, RSA. Available from: www.dwaf.gov.za/Documents. [Accessed October 22 2006].

Ekins, P. 1995. Economics and Sustainability. In: ed. Ravaioli, C., Economists and the Environment. Zed Books, London, UK.

Enfors, E.I., and L.J. Gordon. 2007. Analyzing resilience in dryland agro-ecosystems: a case study of the Makanya catchment in Tanzania over the past 50 years. *Land degradation and development* 18:680-696.

Faber, M. 2005. Complementary foods consumed by 6-12-month-old rural infants in South Africa are inadequate in micronutrients. *Public Health Nutrition* 8(4):373-381.

Faysse, N. 2004. An Assessment of Small-scale Users' Inclusion in Large-scale Water User Associations of South Africa. [Internet]. Research Report 84. International Water Management Institute, Colombo, Sri Lanka. Available from: http://www.iwmi.cgiar.org/pubs/pub084/RR84.pdf. [Accessed: 23 October 2006].

Fox, P and Rockström, J. 2003. Supplemental irrigation for dry-spell mitigation of rain-fed agriculture in the Sahel. *Agricultural Water Management* 1817:1–22.

Frankenberger, TR, Stone, MP, and Saenz de Tejada, S. 1989. [Internet]. Household vegetable gardens in Africa: Case studies from Mauritania and Lesotho. Available from: http://ag.arizona.edu/OALS/ALN/aln29/frank.html#vegles. AridLands Newsletter, No. 29, Fall/Winter 1989. [Accessed 3 December 2006].

Hatibu, N, Mahoo, HF, and Kajiru, GJ. 2000. The role of RWH in agriculture and natural resources management: from mitigation of droughts to preventing floods. In: ed. Hatibu, N and Mahoo, HF, *Rainwater harvesting for natural resources management: A planning guide for Tanzania.* Technical Handbook No. 22. RELMA, Nairobi. 58-83.

Henriksson, J. 2004. Mapping Small-holder Farmers Use of Ecosystem Goods in Potshini, Thukela Drainage Basin, South Africa: Focus on Times of Crop Failure. Unpublished MSc Dissertation, Department of Systems Ecology, Stockholm University, 106 91 Stockholm, Sweden.

Herr, K. and Anderson, G.L. 2005. *The Action Research Dissertation: A Guide for Students and Faculty.* Sage Publications, London, UK.

Holling, CS. 1986. The resilience of terrestrial ecosystems: local surprise and global change. In: ed. Clark, WC and Munn, RE, *Sustainable Development of the Biosphere*. Cambridge University Press, Cambridge, UK, pp. 292–317.

Hurni, H. 2000. Assessing Sustainable Land Management. *Agriculture, Ecosystems and Environment* 81, 83-92.

Irrometer Co. 2006. Moisture Sensor Agricultural Irrigation Design Manual. [Internet]. Irrometer Co., Irrigation Association, Riverside, CA, USA. Available from: http://www.irrometer.com/pdf/ADG.PDF. [Accessed: 22 October 2006].

Jones, PG; and Thornton, PK. 2003. [Internet]. Spatial Modeling of Risk in Natural Resource Management. *Conservation Ecology* 5(2):27. Available from: http://www.ecologyandsociety.org/vol5/iss2/art27/. [Accessed: 16 October 2006].

Kropff, MJ; Bouma, J; and Jones, JW. 2001. Systems Approaches for the Design of Sustainable Agro-Ecosystems. *Agricultural Systems* 70:369-393.

Kruger, E. 2006. Personal communication. Independent Development Practitioner. Peitermaritzburg, RSA, 14 October 2006.

Lal, R. 1991. Current research on crop water balance and implications for the future. In eds: Sivakumar MVK, Wallace JS, Renard C, Giroux, C, *Proceedings of the International Workshop of Soil Water Balance in the Soudano Sahelian Zone*. Niamey Niger. IAHS Publication No. 199. IAHS Press, Institute of Hydrology, Wallingford, UK.

Ngigi, SN. 2003. What is the limit of up-scaling rainwater harvesting in a river basin? *Physics and Chemistry of the Earth* 28: 943–956.

Ngigi, SN, Savenije, HHG, Rockström, J and Gachene, CK. 2005. Hydro-economic evaluation of rainwater harvesting and management technologies: Farmers' investment options and risks in semi-arid Laikipia district of Kenya. *Physics and Chemistry of the Earth* 30:772-782.

O'Brien, R. 2001. An Overview of the Methodological Approach of Action Research. In Roberto Richardson (Ed.), *Theory and Practice of Action Research.* João Pessoa, Brazil: Universidade Federal da Paraíba. (English version) Available from: www.web.net/~robrien/papers/arfinal.html#_Toc26184652. [Accessed 13 October 2008].

Oweis, T and Hachum, A. 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management* 80(1-3):57-73.

Pachepsky, Y, Radcliffe, DE, and Selim, HM. 2003. *Scaling methods in soil physics*. CRC Press, Boca Raton, FL, USA.

Perrings, C. 2006. Resilience and sustainable development. *Environment and Development Economics* 11:417-427.

Postel, S. 1999. *Pillar of sand: can the irrigation miracle last?* W.W. Norton and Co. New York, USA.

Pound, B; Snapp, S; McDougall, C; and Braun, A. 2003. [Internet]. Managing Natural Resources for Sustainable Livelihoods: Uniting Science and Paricipation. Earthscan/IDRC. Available from: http://www.idrc.ca/en/ev-34000-201-1-DO_TOPIC.html. [Accessed 12 September 2006].

Pretty, JN. 1995. *Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance*. Earthscan Publications Ltd., London, UK..

Rijsberman, FR and Manning, N. 2006. [Internet]. Beyond More Crop per Drop: Water Management for Food and the Environment. 4th World Water Forum. Available from: http://www.iwmi.cgiar.org/WWF4/html/index.htm [Accessed 13 October 2006].

Rockström, J. 2000. Water resources management in smallholder farms in eastern and southern Africa: an overview. *Physics and Chemistry of the Earth* (B) 25 (3):275–283.

Rockström, J. 2003. Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth 28*(20-27):869-877.

Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning de Vries, F., Rwehumbiza, F., Sally, H., Savenije, H., Schulze, R. 2004. A watershed approach to upgrade rain-fed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Physics and Chemistry of the Earth* 29:1109–1118.

Saenz de Tejada, S. 1989. *Food consumption and its relation to production: a survey in Lesotho*. Nutrition in Agriculture Cooperative Agreement, College of Agriculture, The University of Arizona, Tucson.

Sandor, JA and Furbee, L. 1996. Indigenous knowledge and classification of soils in the Andes of southern Peru. *Soil Science Society of America Journal* 60:1502–1512.

Schmidt, MI, and Vorster, HH. 1995. The effect of communal vegetable gardens on nutritional status. *Development Southern Africa* 12: 713-734.

Scoones, I; and Thompson, J. 1994. Beyond Farmer First: Rural people's knowledge, agricultural research and extension practice. Intermediate Technology Publications Ltd. London, UK.

Sivakumar, MVK, Wallace, JS. 1991. Soil water balance in the Sudano-Sahelian zone. In eds: Sivakumar, MVK, Wallace, JS, Renard, C and Giroux, C, *Proceedings of the International Workshop of Soil Water Balance in the Sudano-Sahelian Zone.* Niamey, Niger. IAHS Publication No. 199. IAHS Press, Institute of Hydrology, Wallingford, UK.

Smith, HJ, Trytsman, G, Bloem, JF, Everson, T, and Mthethwa, S. 2005. Development and Implementation of Sustainable Land Management Practices in the Bergville District of the KwaZulu-Natal Province. ARC-ISCW Report Number GW/A/2005/04. Fourth Progress Report to the KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara, RSA.

Smith, HJ, Trytsman, G, Dlamini,TC, Bloem, JF, and Agrella, K. 2004. Development and Implementation of Sustainable Land Management Practices in the Bergville District of the KwaZulu-Natal Province. ARC-ISCW Report Number GW/A/2004/07. Third Progress Report to the KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara, RSA.

Smyth, AJ and Dumanski, J. 1993. FESLM: an international framework for evaluating sustainable land management. World Soil Resources Report no. 73. FAO, Rome.

Steiner, K; Herwig, K; Dumanski, J. 2000. Practical and cost-effective indicators and procedures for monitoring the impacts of rural development projects on land quality and sustainable land management. *Agriculture, Ecosystems and Environment* 81:147-154.

Stirzaker, R, Stevens, J, Annandale, J, Maeko, T, Steyn, M, Mpandeli, S, Maurobane, W, Nkgapele, J, and Jovanovic, N. 2004. Building Capacity in Irrigation Management with Wetting Front Detectors. Water Research Commission. WRC Report No. TT 230/04. Gezina, RSA.

Stone, MP, Perquin, B, and Hamidou, S. 1987. *Vegetable production along the Senegal River: a reconnaissance survey of gardens in the Brakna and Gorgol regions*. Mauritania Agricultural Research Project II, College of Agriculture, The University of Arizona, Tucson.

United Nations Statistics Division. 2005. Press Release/Pop 918: World Population to Increase by 2.6 Billion Over Next 45 Years, with All Growth Occurring in Less Developed Regions. [Internet]. United Nations Department of Economic and Social Affairs. Available from: http://www.un.org/News/Press/docs/2005/pop918.doc.htm. [Accessed: 15 August 2006].

Van Genuchten, M. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am.* 44:892-898.

Walker, JW. 2005. Assessment of Agro-Ecosystem Sustainability Across Varying Scales in South Africa. Unpublished PhD Thesis, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, RSA.

Wallace, JS. 1996. Water balance of mixed tree-crop systems. In: Ed. Ong, CK, and Huxley, P. *Tree-Crop Interactions: A Physiological Approach.* CAB International, Wallingford, UK.

WinklerPrins, AMGA. 1999._Local soil knowledge: a tool for sustainable land management. *Society and Natural Resources* 12:151–161.

World Food Summit. 1996. Rome Declaration on World Food Security and World Food Summit Plan of Action. [Internet]. Food and Agriculture Organization of the United Nations, Corporate Document Repository. Available from: http://www.fao.org/docrep/003/w3613e/w3613e00.htm. [Accessed 15 August 2006].

CHAPTER TWO

First Publishable Paper

Building an understanding of water use innovation adoption processes through farmer-driven experimentation

Submitted to Physics and Chemistry of the Earth

Building an understanding of water use innovation adoption processes through farmer-driven experimentation

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Abstract

Smallholder farmers in Southern Africa are faced with the challenge of securing their livelihoods within the context of a wide variety of biophysical and socio-economic constraints. Agriculture is inherently risky, particularly in regions prone to drought or dry spells, and risk-averse farmers may be viewed by researchers or extension agents as reluctant to invest in agricultural innovations that have potential to improve their livelihoods. However, farmers themselves are more interested in personal livelihood security than any other stakeholder and it is the farmers' perceptions of needs, investment options and risks that drives their decision making process. A holistic approach to agricultural innovation development and extension is needed to address both socio-economic and biophysical dynamics that influence adoption and dissemination of innovations. This paper presents a methodology for involving farmers from the Bergville district of South Africa in the process of innovation development through facilitation of farmer-driven gardening experiments. Facilitating farmer-driven experimentation allows farmers to methodically assess the value of innovations they choose to study while providing researchers with a venue for learning about socio-economic as well as biophysical influences on farmers' decisions. With this knowledge, researchers can focus on developing innovations that are socially and economically appropriate and therefore more readily adoptable. The participatory process gave farmers the tools they needed to make informed decisions through critical thinking and analysis and improved their confidence in explaining the function of innovations to others. Researchers were able to use farmers' manually collected data and observations to supplement laboratory generated and electronically recorded information about soil water dynamics to understand water balances associated with different garden bed designs, and to investigate whether trench beds, drip irrigation and water harvesting with run-on ditches tended to improve water use efficiency. Wetting Front Detectors were shown to have some potential as management tools for farmers, provided certain limitations are addressed, while drip irrigation was found to be impractical because the available drip kits were prone to malfunction and farmers believed they did not provide enough water to the plants. Farmers participating in a series of monthly, hands-on workshops that encouraged individual experimentation tended to adopt and sustain use of many introduced garden innovations. Farmers who were also seriously involved in a formalized research and experimentation process at their own homesteads became more proficient with gardening systems in general, through continual trial-and-error comparisons and making decisions based on observations, than those who were not involved. This suggests that the practice of on-going experimentation, once established, reaches beyond the limits of facilitation by researchers or extension agents, into the realm of sustainable change and livelihood improvement through adoption, adaptation and dissemination of agricultural innovations.

Keywords: Innovation adoption, Participatory research; Smallholder farmers; Trench beds; Water harvesting

1. Introduction

A thirty-five year old woman with four children, a grandchild, two chickens and five geese is head of a household in rural South Africa. Her husband only returns home on holidays, as he works in a factory three hours away and sends remittances home to help provide for them. A traditional healer with five cows, whose wife left him to care for their two children alone earlier in the year. A young husband and wife with a baby living together in one of several homes at a larger family homestead. They work the crop fields together with the rest of the family as they have not been allotted their own parcel. How do these people, all members of the same subsistence farming community, make decisions about trying, adopting and adapting agricultural innovations? Is it reasonable to assume they are each influenced by the same factors because they are from the same culture and live in the same village? How do their differing socio-economic situations influence the decisions they make? Answers to these questions are not straight forward, and an approach to building an understanding of innovation adoption in a diverse community requires an integrated, flexible and participatory strategy.

The research for this project was part of the Smallholder Systems Innovations (SSI) project, a research initiative aimed at implementing and assessing the potential social and agrohydrological impact of water related innovations based in Potshini, a Zulu subsistence farming community in the Okhahlamba Municipality of the Bergville district in South Africa. The Potshini community is comprised of around 400 Zulu homesteads and covers approximately 2.5 km^2. Mean annual precipitation is estimated at approximately 700 mm/year and precipitation falls primarily during summer months, from September to May. Winters are cold with regular frost from early May to late August and occasional snow. Strong, dry winds are experienced in August and September. A number of boreholes with hand pumps provide water for domestic use, along with small streams that also replenish reservoirs for downstream commercial farmers. Stream flows are extremely low during winter months.

According to 2001 census data, 58% of people over the age of twenty in the Okhahlamba Municipality (population 137,525) have received some level of education, but only 4% have received higher education while the rest of the population (38%) has had no schooling (Statistics South Africa, 2001). In addition, 56% of the population over the age of 5 can be classed as functionally illiterate. (Okhahlamba Local Municipality, 2007). In the Okhahlamba Municipality, 33.5 % of women attending antenatal clinics are HIV positive, 59.3% of children live in poor households and 60% of people over the age of 20 are unemployed. The majority (80%) of people live on tribal lands, while the remaining 20% live in freehold land areas or commercial farms (World Vision, 2003).

A number of agricultural innovations have been introduced in the area over the past seven years by university, government and non-government organizations. The common goal of such initiatives has been to improve livelihoods and conserve natural resources within the community. However, such goals are not attainable if community members do not adopt and disseminate the innovations. Development projects in sub-Saharan Africa have often been unsuccessful because they have introduced practices that community members did not perceive to be immediately relevant (Quinn, et al., 2003). In addition to a lack of perceived relevance, documented reasons for the failure of farmers to adopt innovations include complexity of the technology, conflicting information, institutional factors, risk associated with the new practices, lack of flexibility, implementation costs (both capital and intellectual), and incompatibility with other aspects of farm objectives or management, or with physical or social infrastructure (Vanclay and Lawrence, 1994; US EPA, 2000). Other factors identified as having potential to influence farmers' decisions about innovation adoption include age, gender, farm size, annual income, education and experience (Bengesi *et al.*, 2004). In addition, a study conducted by Meinzen-Dick (2003) revealed that farmers' attitudes toward, and trust in, extension institutions play a key role in either hindering or facilitating dissemination processes. Some of these documented factors are related to biophysical circumstances, but the majority of them are of a socio-economic nature.

It has been increasingly recognized that in areas where agriculture is constrained by poor rainfall distribution and partitioning, innovations that increase rainwater use efficiency, often involving rainwater harvesting and management strategies, have great potential for improving livelihoods and increasing food security (Rockström, 2000; Rockström, 2003; Ngigi *et al.*, 2005). In small gardens, such innovations are focussed on the conservation of soil water which has been shown to increase crop yield and minimise the labour effort of the farmer. However, investing in agricultural innovations is inherently risky, particularly in semi-arid regions prone to drought or dry-spells. Farmers may be viewed as being slow or unwilling to invest in their own livelihood by development agents who do not understand the decision-making processes or investment options available to community members. In reality, the farmers themselves are more interested in improving their own livelihoods than any external agent might be, but their decisions are constrained by risks and uncertainties associated with past experiences and limited options (Ngigi, 2005).

Farmers in South Africa have many risks, goals, limitations and options to consider when making decisions, as demonstrated in Fig. 2.1. For a farmer to accurately decide that an innovation is worthy of investment, they should have a realistic understanding of its risks and benefits. This will help them avoid wasting resources on an innovation that is not suited to their specific situation, which could lead them to build reluctance toward trying other potentially beneficial innovations. Facilitation of farmer-driven experimentation provides a platform from which researchers can build an understanding of the factors influencing farmers' decision making processes while at the same time gives farmers an opportunity to aid in the development and adaptation of innovations that are relevant to their situation. Through this process farmers can gain insight into the value of different innovations and develop their own methodology for experimenting with new ideas and comparing them to traditional practices. In rural areas where the level of education is relatively low, developing critical thinking skills through experimentation has the potential to contribute to long term well being through increasing a farmers self confidence and ability to adapt to a changing environment, long after researchers and extension agents have left the area.

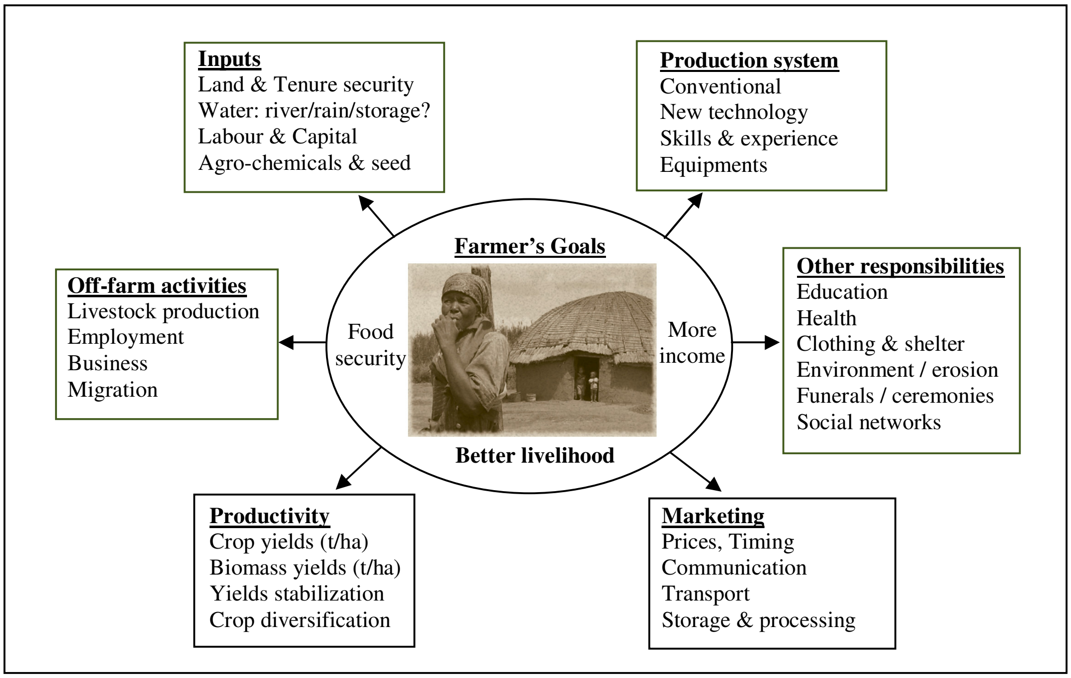

Fig. 2.1. Factors influencing farmer's decision making process in rainfed agricultural systems in Southern Africa (after Ngigi *et al.,* 2005).

In this paper, a methodology for building an understanding of innovation adoption and dissemination processes through facilitation of farmer-driven gardening experiments that can be complemented by technical research to reveal appropriate, adoptable innovations is presented. The methodology focuses on fostering farmers' critical thinking and ability to adapt their own agricultural practices to improve their livelihoods within the context of a changing environment. Biophysical factors are reviewed and socio-economic factors that have been found to influence farmer's decision making in Potshini are discussed. Biophysical data were measured in some farmers' gardens in conjunction with meterological data obtained from the broader Potshini monitoring network (Kongo and Jewitt, 2006). Thus, results of collaborative research are also outlined in terms of the water use efficiency (WUE) of innovations selected by farmers for experimental trials. Finally, a set of conditions required for successful and efficient adoption, adaptation and dissemination of agricultural innovations and possible pathways (including farmer-driven experimentation) for facilitating innovation adoption are presented.

2. Research methodology

2.1. Participatory Techniques

Various Participatory Learning and Action (PLA) research techniques were implemented throughout this study in order to acquire information about farmers' perceptions, and because PLA techniques have been shown to foster metacognitive and critical analysis skills of the participants (Shahvali and Zarafshani, 2002). As part of the PLA process, SSI research funds dedicated to "Outreach Activities" were used to facilitate a series of Farmer Learning Workshops (FLWs) that were organized in conjunction with a development initiative sponsored by South Africa's Water Research Commission to design training materials for water use in homestead farming systems (RIE, 2008). A total of 9 workshops, open to all community members, were held on a monthly basis, each time at a different local homestead. They focused on a number of organic gardening practices (including mulching, pest control, tower gardens, bed design, irrigation, water harvesting, etc.), encouraged farmer-driven experimentation and included previous workshop reviews and group assessments of each others work and progress. Along with the workshops, two Farmer Learning Groups were established, each with a leader farmer elected by group members. Leaders helped organize workshops and communicated group goals and questions to SSI and WRC facilitators. They also assisted group members with implementing and understanding introduced innovations. At the onset of the FLW initiative, facilitators walked from house to house inviting community members. Although workshops were open to the community, workshop date announcements were spread by learning group leaders after the first workshop, which left some community members uninformed about upcoming workshops.

The primary method of gathering information about socio-economic, as well as biophysical influences on farmers' decision making were case studies conducted over a 9 month period. Six homesteads participating in the FLWs were chosen as case studies because the number allowed researchers to collaborate with farmers from a range of socio-economic backgrounds while limiting the amount of time required for homestead visits to a manageable level, thereby allowing 2 to 3 visits to each homestead per month. Regular facilitation visits were important in terms of building an understanding of socio-economic influences on those six farmers' decisions. While the sample size was small and therefore not representative of the community as a whole, influences affecting these few farmers provided valuable context for understanding the results of interviews and group PLA activities that involved a much broader range of farmers. However, despite efforts to work with a sample that represented the community accurately, it is likely that some members' socio-economic influences were not accounted for, particularly for the "poorest of the poor" who may have been too sick or too pre-occupied to have been involved in any learning groups or interviews. Case studies were initiated and implemented as outlined in Table 1. Several types of PLA techniques were applied through the case study process, including informal discussions, work sharing (taking part in local work and activities), villager presentations, process notes and personal diaries, direct observation and semi-structured interviews. PLA techniques designed to reach a broader range of community participants included matrix scoring, semi-structured interviews, group discussions and key informants. Fifty-five structured interviews were conducted with the aid of local interpreters to augment information gathered through participatory methods. Informal interviews were conducted with other stakeholders having a vested interest in the wellbeing of the community, including non-government organization (NGO) workers and project leaders for other research and development groups who have worked in Potshini. These techniques were employed with the aim of working with and fostering communication between stakeholders within the community. The local agricultural extension officer was invited to participate in all group gatherings associated with this project and members of local NGO's were often invited to attend as well, in order to share knowledge and promote communication. Stakeholder communication aided in building an understanding of factors that influence farmers' decisions about adopting new technologies. However, communication between stakeholders had been relatively poor in the past, and organizing meetings between the various stakeholders proved to be time consuming and sometimes frustrating.

Table 1
Case study process and timeline

Activity	2006 Q3	2006 Q4	2007 Q1	2007 Q2
Identification of farmers	■			
- Attend Farmer Learning Group gardening workshops (initiated prior to project research)				
- Meet with leader farmer to discuss which farmers may be interested in participatory experimentation & variation in farmers' economic & social standing				
- Introduce idea of participatory experimentation to Farmer Learning Groups				
- Meet with 6 farmers of various social & economic standing (identified with help of leader farmer) to invite them to participate in experimentation process. Offer to help with gardening issues & techniques learned in workshops.				
Experiment initiation & garden bed preparation		■		
- Preliminary garden visits / sketches				
- Discuss possible experiments with farmers				
- From the primary 6 gardens, identify 4 gardens suitable for technical experiments by assessing farmers' interest & available time				
- For the 4 identified farmers, suggest various technical experiments using innovations learned in garden workshops. Farmers chose to compare innovations they were most interested in to traditional way of planting				
- Facilitate the comparison of learned innovations to traditional planting through observation & note-keeping (non-technical) with all 6 farmers				
-Create and distribute field notebooks (calendars, data forms, example experiment outlines, garden photos) to the 6 farmers				
- Assist farmers in constructing 60 cm trench bed in 2 gardens				
- Install drip kit at 1 of the 60 cm trench beds (with help from farmer)				
- Farmer constructed 25 cm trench bed in 1 garden				
- Construct ditch system for collecting and distributing run-on at 1 garden (with help from farmer)				
Installation of technical equipment (with minor assistance from farmers)		■		
- Install manual rain gauges at all 6 gardens				
- Set up 2 pairs of Wetting Front Detectors in each of the 4 identified gardens				
- Install 2 nests of Watermark® sensors in 3 of the 4 gardens				
- Install 2 Capacitance Probe tubes in 3 of the 4 gardens				
Interviews & PLA		■	■	■
- Meet with the 6 identified farmers individually to discuss garden issues/progress bi-monthly (at least)				
- Structured interviews with 55 farmers				
- Personal diaries & process notes				
- Informal communication & semi-structured interviews				
- Matrix scoring activity (value ranking development projects)				
- Attend community & stakeholder sponsored meetings				
- In response to individual and group interest, assist an existing co-op with application for donated hydroponic green house & organizing entrepreneur training / mentoring				
- Group discussions & learning process evaluations				
Instrumentation monitoring & data collection		■	■	■
- Bi-monthly data downloads at 3 gardens with full technical instrumentation				
- Quality check & photograph farmer data records at 4 gardens doing technical experiments bi-monthly				
- Discuss garden notes and records with all 6 farmers monthly				
- Soil sampling & characterization tests (minor assistance from farmers)				
Information sharing				■
- Farmer to farmer presentations (about their garden experiments)				
- Researcher to farmer presentation (about experimentation process & findings)				

Using trial plots has been shown to have positive effects on agricultural innovation adoption because it provides information that reduces uncertainty while promoting skill development in relation to the innovative practices (Abadi Ghadim, 2000). During the course of this project, all trials for comparing WUE of new innovations to traditional practices were based at individual homesteads, rather than using a "mother and baby" trial design with a large researcher-driven trial plot for training, as described in (Snapp, 1999). This eliminated the problem of motivating people to work in the researcher's trial plot through monetary or other incentives that could detract from the intended educational outcomes. It was also done in an attempt to focus the research on farmers' interests and to foster a sense of ownership of the experimentation process. Through this ownership, farmers themselves became the "experts" which gave them the confidence to use their own gardens as demonstration plots to help disseminate knowledge gained through the trials to other community members.

2.2. Technical Instrumentation

In order to assess the WUE of the different innovations, a range of technical instruments were placed in the gardens of the six farmers chosen for detailed case studies. These tools included manual reading rain gauges, Wetting Front Detectors (WFDs), nested Watermark® sensors (WMS), and Capacitance Probe tubes. The WFD is a mechanical instrument which "activates" a pop-up signal when water in the form of a "wetting front" resulting from rainfall or irrigation passes a certain depth, as illustrated in Fig. 2.2. WMSs, used to measure soil water tension, and the Capacitance Probe, which measures water content, provide digital signals in response to different soil water characteristics at different depths which can be stored with micro-computer equipment (loggers). WFDs were particularly useful in terms of participatory learning because they are a technical tool that is not electronic and they provide an immediate visual signal, allowing farmers to see when the soil has become saturated at certain depths.

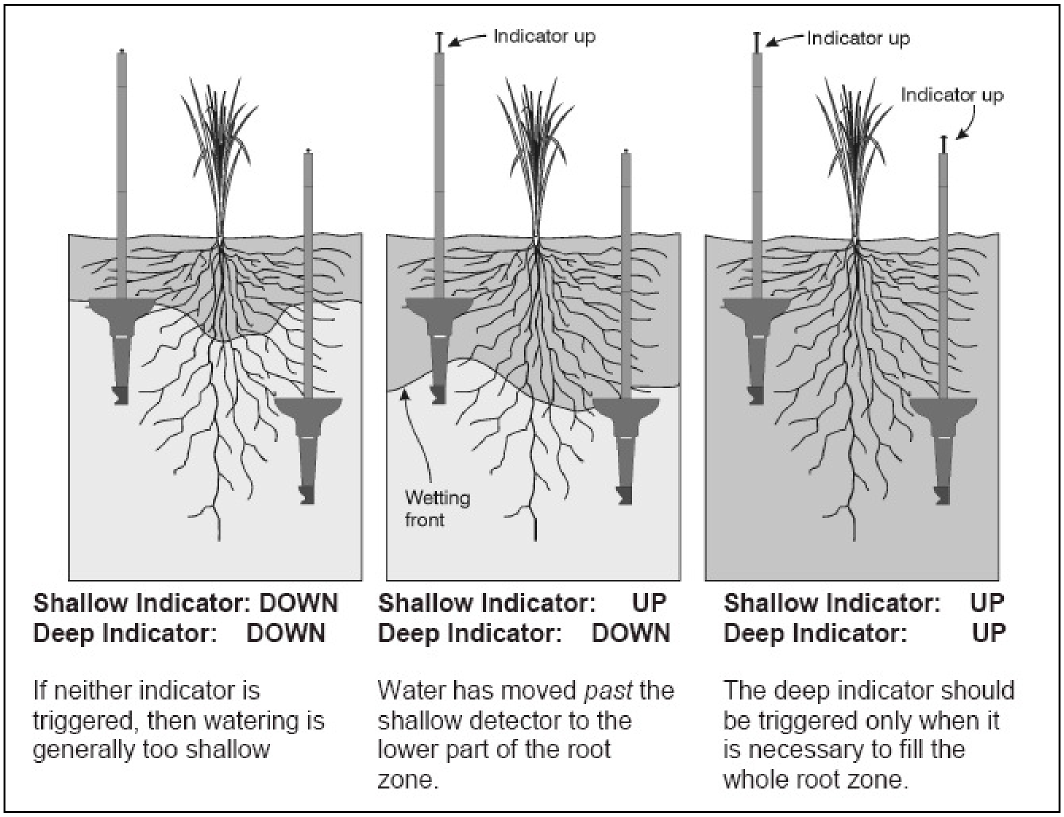

Figure 2.2: Idealized diagram of Wetting Front Detector activation process (Stirzaker *et al.*, 2004).

All six farmers were provided with rain gauges and encouraged to conduct their own experiments by comparing new gardening methods and ideas to traditional planting techniques, but only three of the six gardens were outfitted with the entire set of technical instruments. These three farmers were requested to record daily rainfall, irrigation timing and quantity and WFD activation events. Information from technical tools was supplemented with laboratory generated soil analyses and in-field soil hydraulic characterization tests. Data provided by these tools were used to estimate changes in water balances for different garden bed designs over the summer season. This aspect of the initiative is described in detail by Sturdy *et al*. (in preparation). The data was also intended to provide farmers with a means for understanding the optimal times to irrigate and how much water should be applied during irrigation events for the various bed designs and irrigation methods chosen for experimentation.

Trials chosen by farmers involved comparisons of traditional techniques to garden bed designs and irrigation technologies recently introduced through the FLWs. These included trench beds, constructed by digging a 60 cm pit and filling it with layers of local grass, manure and soil. Also chosen were manually constructed run-on ditches, designed to direct local rainwater runoff into the garden and around the beds using gravity and a network of level, 20 cm deep ditches with check-dams and overflow outlets. The third technology chosen for structured experimentation was a drip irrigation kit, used to conserve water by irrigating directly at the base of individual plants with a slow drip from a network of plastic pipes. Specific trial designs are outlined in Sturdy *et al*. (in preparation).

Due to the small sample size and the nature of working collaboratively in farmers' homesteads while encouraging farmers to drive the experimentation process, trials were less controlled than they could have been otherwise. For example, only one run-on ditch trial was tested, while the two trench bed trials were conducted in different soil conditions that cannot be directly compared to one another. In addition, the crop cover between experimental beds and control beds varied significantly because farmers did not have much space in their gardens (due to lack of fencing material) and they preferred to plant when the bed and the seedlings were available rather than waiting to plant both control and experiment beds at the same time with the same number and type of seedlings.

3. Results and discussion

3.1. Pitfalls of previous initiatives

A communal garden was introduced to the area by the Child Survival Programme, but it is no longer operating and was fairly unsuccessful at the onset because participants were chosen due to malnutrition and vulnerability of their children, rather than for their interest in gardening (Kruger, 2006).

Between 2000 and 2004 a government "LandCare" project introduced conservation tillage, crop rotation and intercropping with legumes (especially soybean), liming, grazing management and other conservation agricultural methods. A "mother and baby" type of trial design (Snapp, 1999) was implemented and Action Research techniques such as action planning, look-and-learn, focus groups, role play, brainstorming, and learning-by-doing were employed to involve farmers in the learning process. Regular farmer forums were also organized to promote knowledge sharing between farmers and to facilitate planning for the LandCare initiative. After four years of working with LandCare, 19 leader farmers had trained 217 additional farmers how to implement various conservation agriculture innovations. The LandCare project team claimed that conservation agriculture had a highly positive impact on crop production (maize yields more than doubled in the 3 years of practicing), soil health, household food security and social wellbeing of farmers (Smith *et al.*, 2005).

One year after the LandCare project finished its work in the Potshini area, the farmer forums had dwindled and many of the participants had ceased to use the minimum tillage practices. Interviews with 55 community members conducted as part of this project showed that 29% had tried minimum tillage but that only 15% continued to use the method, and of those farmers many were not using it on all of their land or were still using donated inputs. Other practices introduced by LandCare, such as herbicide, were still being used by up to 22% of the farmers. The reasons for this are not entirely clear, but some factors that arose during a number of interviews and informal discussions with community members included:

- Soybeans have an unpleasant taste, and farmers don't have an easy way of processing them.
- Lab-lab beans are easier to process than soybeans, but they do not seed before the cattle return to the fields at the end of the growing season so it is nearly impossible to keep a stock of seed.
- Inputs (herbicide, fertilizer, seed, and equipment) were given to participating farmers throughout the life of the project, but after the project ended many farmers did not feel they could afford to purchase inputs.
- Some farmers were paid for participation/labour during parts of the learning process and may have regarded the project as a job more than a training opportunity.
- Correct timing of the conservation tillage procedures taught through LandCare is important and farmers who missed the start date for various reasons would abandon the practice entirely for that year.
- New mechanical equipment is not available to the community (because of the cost of importing it), and equipment provided by LandCare was not functioning properly so labour was done by hand, resulting in an overall increase in labour.
- Removing weeds rather than tilling increased required labour significantly, especially when herbicide was not applied at the right time.

- Required labour was reported to be very high, though it was recognized that it would not be so high if the proper equipment and herbicide was available at the appropriate time.
- Livestock eat all plant residue and compact soil by walking on it.
- Many people want to see an innovation working before they will try it themselves.

In addition to these factors, maize (the primary crop grown) is not a high value crop and most of the community members have little to no experience with marketing and selling their crops. Some farmers have to pay to store surplus maize in town 10 km away because there is no place to keep it at their homestead. Farmers definitely recognized that conservation tillage increased yields significantly, but if surplus cannot be sold for a profit, especially when it costs to store it until the family can eat it, there is little chance that increased yields will result in sufficient funds for purchasing inputs the following year.

3.2. Case studies

The original six farmers participating directly in this study were chosen with an effort to involve people from diverse backgrounds, however, of those six farmers, the three who were chosen for technical experimentation were selected based on an expressed willingness and level of literacy (required for taking notes and keeping records). Throughout the learning process, farmers were encouraged to choose the innovations they wished to experiment with. Although a number of gardening innovations were suggested, the research trials were designed around the interests of the farmers, not necessarily the interests of the researcher. After the first month it became clear that two of those three farmers would keep daily records, while the third farmer was less interested in working in her garden in general and would only occasionally record observations. Of all six farmers participating in the farmer-driven experimentation process, three women improved their gardening skills considerably throughout the research period, farmer S, farmer N, and farmer D (with help from her husband). These three have very different social situations, but all three are hard working, healthy young adults. The two men and the other woman who participated did not make much time for their gardens or the learning process due to other activities including local employment.

3.3. Biophysical Factors Affecting Innovation Adoption and Dissemination

Problems and risks influencing decision making in the community were identified through interviews, discussions, group discussions and matrix scoring, as well as meteorological and soil water data collection and analyses. Biophysical influences on innovation adoption include climate constraints, such as hail, frost and lack of rain in winter, as well as dry spells occurring during the summer growing months. Soils tend to be quite acidic and many fields have been limed using inputs (equipment and lime) provided by government initiatives to reduce acidity. Repeated ploughing and grazing has resulted in soil and nutrient loss. Bacterial and fungal diseases as well as insect, rodent and bird problems have been reported by local farmers. Water is recognized as a limiting factor for farming and gardening in the area and farmers participating in a matrix scoring activity chose water conservation as one of the most important criteria for ranking the value of development projects. Farmers reported that public pumps, springs and creeks in the area are not adequate for large scale irrigation. Erosion due to overgrazing is apparent in and around the community. Fodder shortages are experienced most years, especially when there has been snow.

3.4. Social Factors affecting Innovation Adoption and Dissemination

Farmer experimentation reflects the farmer's own will, it is driven by a certain attitude on the part of the farmer that is influenced by a host of socio-cultural circumstances (Hocdé, 1997). Social perceptions (which are commonly tied to cultural beliefs or norms) play a significant role in farmers' decisions to adopt or adapt an innovation. This was demonstrated when subsistence farmers in the Bergville district refused to adopt a certain style of raised garden bed due to its resemblance to traditional grave sites (Holst, 2007). Farmer-identified social issues affecting innovation adoption processes in Potshini include a lack of knowledge about agricultural principles and water harvesting techniques, as well as marketing and commercialization. Limitations due to a shortage of human capital (manpower) were cited with regard to expanding and working crop fields. This is partly due to the large number of working-age adults who are ill from HIV related complications or are working outside of the community. In addition, training from different government, university and non-government projects have not always supported each other, leading to confusion within the community about the "correct" or best innovative methods. For example, low-cost organic methods have been emphasized during Farmer Learning Workshops, while the use of chemicals has been promoted by the Department of Agriculture.

Controlling livestock (cattle, goats, and chickens) is a significant problem in the community. Although cattle are sent into the hills above the village during the summer growing season, they return during the winter, which prohibits production of winter crops. The majority of community members do not own cattle, yet traditionally all cattle are free to graze any un-fenced land. This will become a more serious issue if people gain access to underground water harvesting tanks for irrigating during the dry months in the future, as planned by the South African Department of Water Affairs and Forestry. In addition, goats and chickens roam the area year-round and have caused significant damage to homestead gardens over the past year.

Marra, *et al*. (2003) claim that the different aspects of risk, uncertainty and learning are important for understanding innovation adoption processes. Such aspects include farmers' attitudes toward risk, farmers' perceptions about the riskiness of a technology, the value of delaying adoption until a clear example of success has been witnessed and the value of experimental trials. Each of these aspects is linked to the others and is influenced by socio-cultural factors. One instance of this in Potshini, as explained by a key informant, occurred when rumours about the cost of using lime combined with a lack of understanding of the value of the innovation caused people to delay adoption until the costs and benefits became obvious, despite the fact that lime was provided and applied for free through a Department of Agriculture program.

Dissemination of innovations is a socio-cultural process and a critical component of developing sustainable change in a community. Previous agricultural extension studies have shown that spontaneous spread of innovations occurs almost exclusively through farmer-to-farmer information exchange (Liniger and Critchley, 2007), yet in Potshini farmers have not always shared new ideas with each other.

Interview results combined with informal discussions in Potshini indicate that dissemination from one member of the community to another does happen, but it is neither a fast nor constant process. Farmers who participated in facilitated experimentation through this project were willing to show their gardens to other farmers when asked and could explain what they had been learning from their trials, but after six months of experimentation two of the five participating farmers had not taught anyone else about innovations they had tried. One said he had taught five family members and neighbors and would teach others if they came to him looking for help. Another had taught family members living within his homestead and a few neighbors. One woman had shown two neighbors how to use mulch and trench beds only.

When farmers are not proactively spreading innovative knowledge, what are the factors that determine whether an innovation spreads throughout a community? According to interview responses collected during this study, farmers tend to adopt innovations learned from a family member more frequently than those introduced by other sources. Interviews showed that 57% of agricultural innovations used by farmers in Potshini were introduced by an immediate family member, while 31% were introduced by government agencies and 7% were introduced by unrelated local subsistence farmers. Fig. 2.3 displays the number of farmers using various agricultural innovations introduced by different sources.

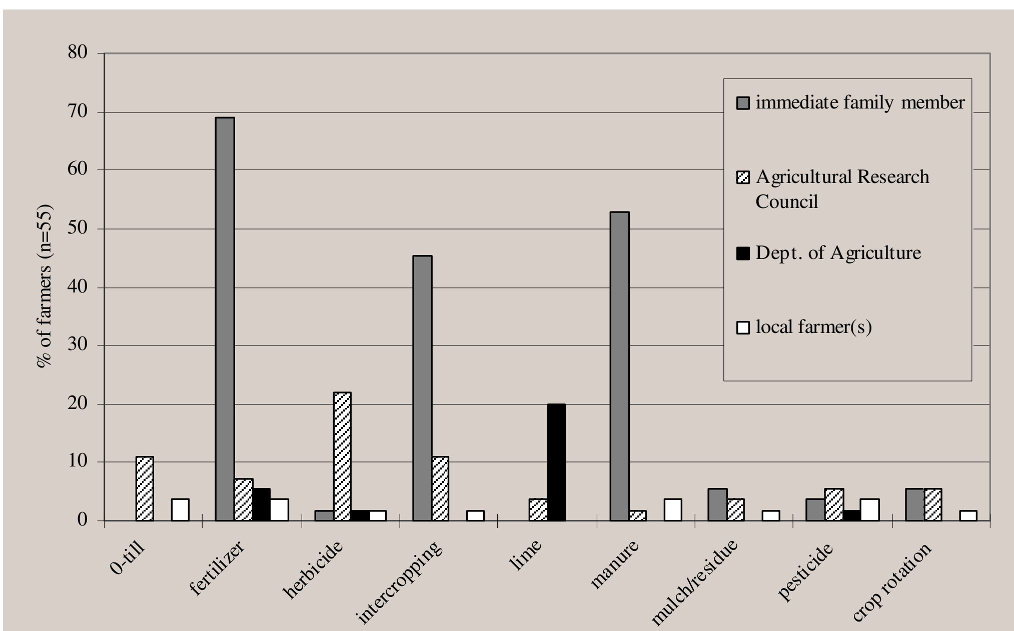

Fig. 2.3. Percentage of farmers using agricultural innovations introduced by different sources in Potshini.

It was expected that innovations pertaining to gardening would have a different distribution of sources than agricultural innovations because gardening is new to the area and most parents or other relatives did not have innovative experience to disseminate. In Potshini, gardening itself is an innovative practice as it has only recently been taken on by community members. The same number of farmers started gardens due to advice from unrelated local farmers (many of whom were FLW group members) as the number of farmers who started due to group participation in FLWs, while few got the idea from a family member (Fig. 2.4). The increased innovation dissemination through local farmer interactions may be related to the social dynamic created through regular learning and knowledge sharing within the context of an organized group.

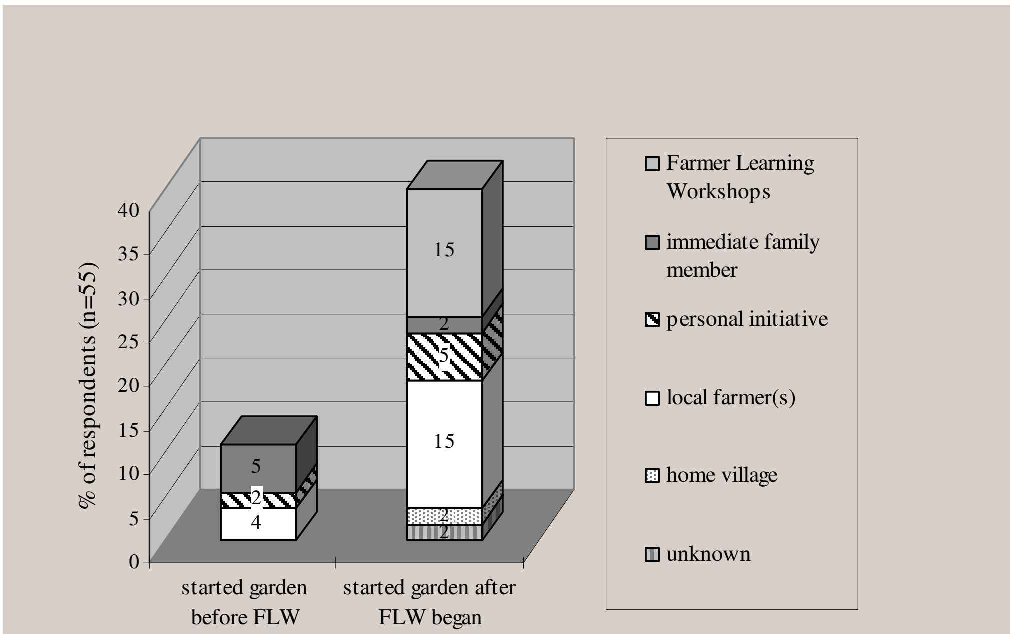

Fig. 2.4. Percentage of farmers who started gardens before or after Farmer Learning Workshops began and the sources that introduced them to gardening.

A survey of 105 farmers in Potshini showed that farmers involved in an organized co-operative or learning group (some 42% of all farmers surveyed) were more likely to start a new practice (in this case gardening) than those who did not belong to any group. Of farmers active in some type of community-based group, 73% had started homestead gardens during or before 2006 (the year FLWs began), while only 26% of people not belonging to any group had started gardening (Kosgei and Jewitt, 2006). There was no clear correlation between adoption of gardening practices and age distribution or number of children within the homestead, however.

Of the farmers participating in FLWs, most had constructed garden sites and attempted to grow some quantity of vegetables within the first six months of workshops. A total of 51% of all farmers interviewed during this project were gardening in January 2007, while only 44% had attended FLWs (n=55). Home visits revealed that the new gardens tended to be relatively small (75% of gardens visited were 20-100 m^2), and only some of the introduced gardening innovations had been attempted. The small size is partly due to a lack of resources, as fencing is required for gardening for protection from local livestock. Innovations that tended to be adopted were those that were simple and did not require a lot of change from traditional/familiar agricultural practices or social norms. Innovations that addressed an immediate problem and provided an obvious benefit were also favoured.

Interviews with 55 farmers in Potshini showed that the use of a solution of chilli and soap dissolved in water to mitigate aphid infestation was used successfully by many farmers who in turn spread the idea to neighbours. This practice is simple, has immediately observable positive effects and can be done using supplies that are generally available in the community. It was also adapted by some farmers who reported to have used the solution successfully with cutworm. A total of 18% of all interviewed farmers were using this solution in their gardents in January 2007. Innovations that required a once-off investment, such as planting fruit trees (used by 24% of interviewed farmers) or constructing a trench bed (used by 25% of interviewed farmers) were also popular, despite the fact that trees had to be purchased and trench bed construction involves a significant amount of labour. Innovations involving complex systems or engineering were not readily adopted. For example, run-on ditches involving a network of level trenches with check-dams and overflow outlets were only adopted by the 9% of interviewed farmers who had assistance with the design in their own garden (either from researchers or from a family member who had already built the ditches in their own garden). Innovations that required monetary input in addition to technical understanding were only adopted by people who had monetary as well as technical assistance. For example, tower gardens designed to utilise grey water efficiently were only constructed by two families, each of which were given all necessary inputs and had assistance with construction. Another example of this involves drip irrigation kits, which were only tried by farmers who were given the kits. The kits themselves, as well as parts to repair the kits were not available in any of the local shops, which precluded the possibility of dissemination. By the end of the project, no farmers were using the kits because the kit was either not functioning properly or because the farmer felt that the kit was not providing enough water as plants irrigated with the kit were observed to wilt more often than those irrigated with a hand-watering system.

It is possible that with time some of the more complex innovations could become widely disseminated, provided community members are exposed to them, are provided educational opportunities to build an understanding of how to utilize them effectively and recognize obvious benefits of using them. However, the nine months allotted for this project's field activities was insufficient for dissemination of such complex innovations. Farmers who adopted the most innovations and developed more productive gardens compared to other FLW members were involved in researcher-facilitated experimentation. This is likely due to encouragement (according to the farmers) and the presence of a researcher/mentor to provide answers to farmer's questions about innovation procedures. However, only two of the six who were initially involved in facilitated experimentation adopted most of the innovations and cultivated relatively large gardens with consistent produce. This reflects the uniqueness of each homestead and the motives that drive each farmer's decisions.

A matrix scoring activity consisting of a group of 7 women and a group of 8 men was conducted in order to identify decision-making criteria used by community members to determine the value of participating in possible development programs (Table 2). The activity revealed that women believed increasing long term household income was the most important role of development projects in the community. This was followed by increasing practical skills and knowledge, and by increasing job opportunities. The men's group also ranked long term income as the top priority, however, they felt that increasing food availability, followed by water conservation were the next most important functions of local projects. Farmer Learning Workshops were not considered in the matrix scoring because, while all women voted for them as an important program, no men voted for them, and as a result the workshops did not have enough overall votes to be considered in the matrix. Similarly, grazing management training was left off the matrix despite being voted for by most men because the women (none of whom own cattle) did not vote for it.

Table 2
Women's group (**bold**) and Men's group (*italicized)* matrix scores for prioritizing community programs.

PROGRAMS / CRITERIA	DoA[a] - agric. training	English literacy	Finance training	Marketing / commercial-ization	Computer training	X-visits	ARC[b] trials
Long term income **(A)**[c,d]	**2** *5*	**5** *5*	**5** *5*	**3** *4*	**5** *5*	**4** *4*	**1** *5*
save water **(C)**[d]	**0** *0*	**2** *0*	**0** *0*	**0** *0*	**0** *0*	**3** *0*	**1** *4*
increase food availability **(B)**[d]	**5** *5*	**1** *5*	**3** *4*	**1** *4*	**5** *3*	**3** *2*	**3** *5*
increase skills / knowledge **(B)**[c]	**3** *4*	**5** *5*	**4** *5*	**5** *0*	**5** *4*	**5** *3*	**5** *5*
increase job opportunities **(C)**[c]	**1** *3*	**5** *5*	**5** *4*	**3** *4*	**5** *5*	**4** *2*	**4** *4*
healthy environment	**4** *5*	**2** *4*	**3** *4*	**0** *2*	**1** *4*	**3** *3*	**2** *5*
improves grazing	**5** *5*	**4** *5*	**5** *5*	**2** **4**	**0** *5*	**5** *4*	**4** *5*
TOTALS:	**20** *27*	**24** *29*	**25** *27*	**14** *18*	**21** *26*	**27** *18*	**20** *33*

[a] The Republic of South Africa's Department of Agriculture
[b] The Republic of South Africa's Agricultural Research Council
[c] **(A)** = voted most important criteria by women's group, **(B)** = 2nd most important, **(C)** = 3rd most important
[d] **(A)** = voted most important criteria by men's group, **(B)** = 2nd most important, **(C)** = 3rd most important

Matrix total scores indicated that the women's group found cross-visits to other farming communities, followed by finance training and English literacy to fulfil elected criteria most comprehensively. However, English literacy ranked highest in terms of the three most valued criteria. English literacy was the second most important program as ranked by the men. The men's group ranked the Agricultural Research Council's (ARC) LandCare conservation agriculture trials as the most valued program, despite the fact that interviews and informal discussions revealed that approximately half of the people who had tried conservation agriculture had later stopped practicing. When questioned, one of the men explained that LandCare has been an important program in the community because Potshini has received a lot of resources since it began and other stakeholders have become aware of community needs and initiated additional programs. For instance, the Department of Agriculture had little to no presence in the community previously but since LandCare started the department has increased extension efforts in Potshini considerably. This is probably due to the ARC's effort to organize farmer forum meetings and involve other stakeholders. It is also likely that ARC trials are favoured because they have resulted in job creation within the community by paying farmers to work on the trials.

3.5. Economic Influences on Food Security and Farmers' Decisions

During a survey of 105 farmers in Potshini, 78% reported that agriculture did not provide sufficient food supplies for their family throughout the year (Kosgei and Jewitt, 2006). Coping strategies listed were all based on receiving monetary income, either through employment or government grants. This indicates that cash flow within the community is critical for sustaining livelihoods. This was reflected in farmers' selection of important criteria during the matrix scoring activity presented above (Table 2), where long term income generation was chosen as the most important aspect of development programs. Accordingly, farmers' decisions about adopting agricultural innovations are closely tied to their perceptions of the input costs as well as the potential for income savings or generation.

A survey conducted by World Vision South Africa (2006) at 378 households in the wider Okhahlamba Municipality confirmed that most families do purchase food and that 65-78% of households do not have sufficient food supplies throughout the year. Borrowing and buying food on credit were cited as coping strategies, while some families reduced expenditure on education and health in order to buy food. Interviews conducted during this study (n=55) in Potshini revealed that 53% of families face regular food shortages, despite coping strategies involving food purchase. Interviews indicated that 67% of families in Potshini purchase most of their food, while only 33% grow most of their food. Farming is still an important aspect of food security throughout the community, however, as an additional 62% claimed that their family obtains a little to some of their food through small scale agricultural production (Fig. 2.5). Homestead vegetable gardening plays a role in food security as well, though it provides significantly less food than either farming or purchasing food. Livestock and eggs from the homestead were only eaten by 9% of the farmers interviewed and then only occasionally. Such figures suggest that diet diversity, and hence nutrition is low in Potshini. These findings are consistent with the 2006 World Vision South Africa survey results, wherein maize was found to be the most common crop by far and the majority of children had very little diet diversity.

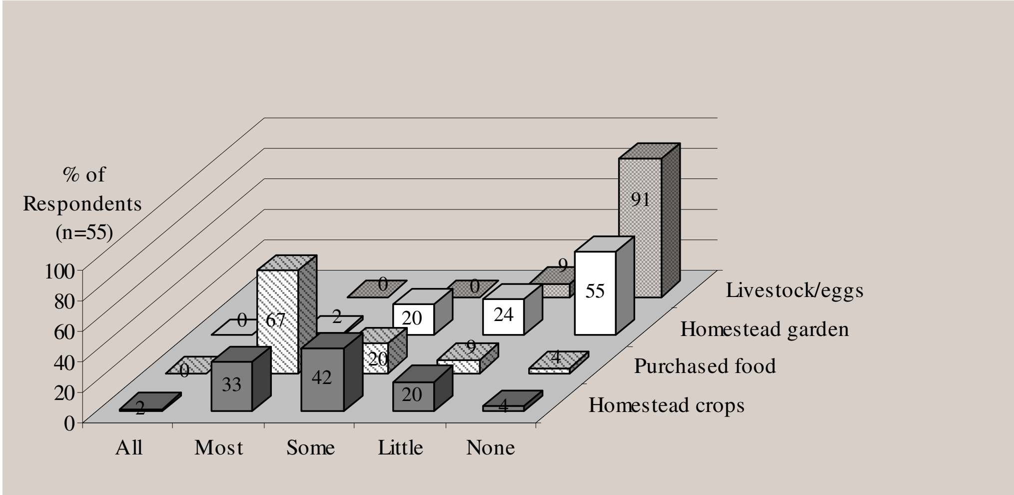

Fig. 2.5. Distribution of food sources in Potshini. Farmers reported either 'all', 'most', 'some', 'little' or 'none' of their family's food came from each of the sources listed.

While the value of homestead gardening in regards to food security has not been quantitatively proven, in the case of at least three of the six farmers participating directly in this study, the garden did have an obvious positive effect on livelihoods. Observed benefits included a continuous supply of diversified vegetable nutrients to the diet, saving money otherwise spent on vegetables and providing income though selling produce to neighbours. For at least one female farmer, an additional livelihood benefit was increased pride in her labours and self confidence in regards to sharing her knowledge with other farmers.

A variety of income sources were reported during interviews conducted for this study, as presented in Fig. 2.6. Pension and welfare grants were the predominant source, followed by remittances and paid labour. Government grants range from R200/person/month to R870/person/month, whereas a family in Potshini spends R941/year on average for agricultural inputs (note that $1 USD equalled approximately R7 at the time of the study). The largest expenditure, however, is that of funerals and ceremonies (weddings, coming of age, etc.), where R10,000 is a typical amount to spend. The large amount required for ceremonies has played a notable role in the economic situation in South Africa (Kruger, 2007). With the rise in HIV-related deaths, funeral services have become a thriving business over the last decade and rural people often pay for funeral insurance prior to a death or become indebted when a death occurs. Cattle are often used as a buffer against the financial shock of a required ceremony or funeral as they can provide the meat required to feed guests or can be sold to pay for other related expenses.

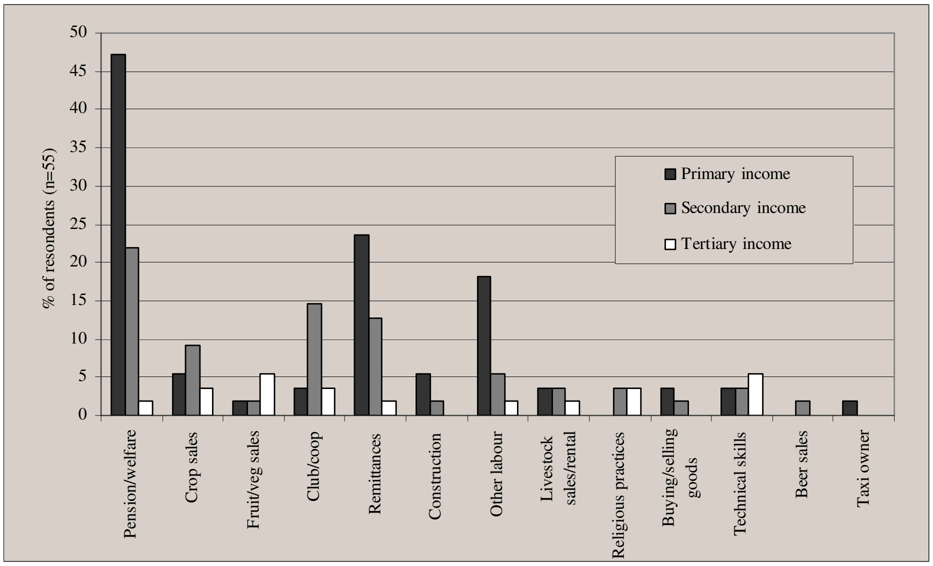

Fig. 2.6. Distribution of primary, secondary and tertiary income sources in Potshini.

With the establishment of a local kenaf processing plant, several Potshini farmers took the initiative to plant their own trial plots with seed provided by the processors in 2006. Farmers were told they would be eligible for a contract to sell to the factory the following year if the current trials produce a good quantity and quality crop. This implies that the extra labour and land used for the 2006-2007 trials would not pay off until the following year, and then only if the trials are successful. Familiarity with the plant (kenaf is related to a naturally occurring local weed), which does not require any new innovations in field preparation, and the prospect of growing a high value crop with a pre-established market are likely factors influencing farmers' decision to risk spending effort on personal trials for this crop.

Other farmer-driven initiatives in the area include two vegetable production co-operatives which received grants for fencing and other inputs at their inception. Both co-operatives have started selling produce to local markets this year but they are struggling with marketing and business management and have recognized a need for entrepreneurship training.

The reasons cited for discontinuing use of an innovation generally involved the monetary cost of innovation upkeep. Labour was also cited as a reason for terminating an innovative practice but only occasionally. All agricultural innovations that were claimed to have been tried but terminated were introduced through the ARC's LandCare project, and required purchasing inputs, such as herbicide or fencing material.

Economic problems identified by farmers during a number of discussions included the inaccessibility and rising costs of agricultural inputs, including the cost of fencing needed to keep livestock from eating and trampling crops, crop residue and vegetables, compacting the soil and contributing to soil erosion. Not surprisingly, local availability and cost of inputs needed for innovations or technologies is one of the most critical determinants for farmers in their choice to adopt a practice. Community and individual needs identified by Potshini residents often addressed economic issues and included business training targeted at saving money, planning, accounting, marketing, computer and English literacy skills. Training leading to income generating skills or projects were frequently requested, such as sewing, driving tractors, raising chickens commercially, and catering.

3.6. Evaluation of collaboratively gathered data

3.6.1. Wetting Front Detectors and the learning process

Farmers were willing if not eager to try using the WFDs. They did not have a good understanding of how the instruments might improve their gardening or irrigation at the onset of the project, but there was no risk involved in placing the instruments so none of the farmers were averse to the idea of trying them out. Farmers were involved in placement of the WFDs and were shown how the instruments are activated. They were then asked to record each WFD activation event, along with irrigation amounts and rain gauge data on provided forms. At this stage some risk was introduced to the process because daily data collection requires valuable time that might be spent on other livelihood activities. In the end, only two of the four farmers using WFDs consistently recorded daily observations throughout the learning process.

In a rural setting, where many farmers have had poor educational opportunities, the significance of soil water holding capacity and wetting fronts can be very difficult to grasp. After six months of facilitated experiments with WFDs, farmers did have good understanding of what the WFD was supposed to be telling them (when the water has reached a certain depth). However, they had only used this information to change their irrigating practices in minor ways. Generally, the farmers said that they knew they could stop irrigating once the WFDs had been activated and did not irrigate again until the WFD indicators could be reset. One woman said that she had changed from irrigating with 10 litres per day to using 20 litres every second day in order to activate the WFDs during each irrigation event. Another farmer noted that the WFDs were only activated after heavy rain and he did not wish to apply enough irrigation to activate them. When questioned, all farmers involved said that WFDs were useful because they "show if there is enough water in the garden". However, by the end of this study, farmers had not fully realized the potential for improving irrigation practices through WFD observations, and could not therefore disseminate an understanding of the true value of WFDs to other farmers in the community. Continuing the facilitated learning process over at least two growing seasons could significantly increase farmers' understanding and use of WFD technology to improve their irrigation schedules. Another limitation of WFDs is that farmers in the Bergville area have no way of procuring WFDs or parts and their use cannot be disseminated until they become more readily available.

3.6.2. Trench beds

Trench bed construction is labour intensive but easily learned. Around half of the farmers who are keeping gardens constructed at least one at their homestead. However, some trench beds were more productive than others (as observed by farmers in Potshini). This is probably due to differences in the original soil composition, as well as the methods of construction. Trench beds that were not filled with water during construction seemed to produce smaller, less healthy vegetables than those that were. In addition, when organic matter such as grass was placed near the top of the trench, plants tended to wilt more easily, possibly due to heat generated by decomposition near the surface of the trench. Because trench beds take time to decompose into mature soil, it is typical to wait two months or more before planting in a newly constructed bed. However, subsistence gardeners may not have much space in their garden and it can be impractical to leave a bed empty for long periods. In Potshini it was found that in most cases vegetables planted immediately after building a trench bed grew well, but it is likely that certain construction methods (such as filling the bed with water during construction, placing several centimetres of soil on the top of the bed, and/or pre-mixing fill materials) would favour immediate planting.

Highly acidic soils are a common problem in the Potshini area and subsurface soil laboratory analyses indicated that traditionally prepared garden beds do tend to be acidic, whereas trench beds generally are less acidic. Trench bed soil samples also contained more phosphorous than control bed samples did (Sturdy *et al.*, in preparation).

Data pertaining to water balances and WUE were sufficient to compare the movement of water within trench beds to that in unmodified soil (control beds). Technical data collected by researchers and the data recorded by farmers provided a set of quality information that was comprehensive and suitable for modelling and interpretation of water balances. Generally, it was shown that trench beds consistently retain more moisture at all rooting depths throughout the rainy season than control beds. With the onset of frequent, prolonged (5 or more days) dry spells late in the growing season, trench beds tended to lose more moisture in the shallower (20 to 40 cm) depths than the control beds, while moisture remained fairly stable at 80 cm in both trench beds and control beds (Sturdy *et al.*, in preparation).

3.6.3. Run-on ditches

Six months after they had been introduced through FLWs, run-on ditches designed to direct water around garden beds using gravity and a network of level trenches with check-dams and overflow outlets were only adopted by farmers who had assistance with the design in their own garden (either from researchers or family members). Run-on ditches were constructed at Farmer D's garden with significant design work and labour provided by researchers. Later in the season, after observing increased water availability in the gardeFarmer D and her husband assisted their brothers and sisters in constructing ditches in their own gardens. Twelve months after introducing run-on ditches, 47% of farmers surveyed (all FLW participants, n=19) by the Water Research Commission in Potshini had constructed some form of run-on ditches, though they were less elaborate than the introduced version, consisting of deep paths around garden beds that held rainwater falling directly into the garden, but with no system for directing runoff from outside the garden into them (RIE, 2008). This suggests that adoption and dissemination of run-on ditches or other complex innovations may be best facilitated through assisting several leader farmers with construction in their own homesteads as part of an on-going workshop/training for all interested community members.

As with the trench bed experiments, researcher and farmer collected data from Farmer D's garden were suitable for modelling and interpretation of water balances and WUE. Data indicated that the garden bed surrounded by run-on ditches consistently retained more moisture throughout the 80 cm profile than the control bed during the rainy season, including short (3 to 5 day) dry spells. However, as dry spells increased in frequency and duration with the transition to the dry winter season, moisture in the run-on ditch bed declined rapidly at all depths, whereas moisture in the control bed declined gradually below 20 cm while maintaining some moisture at 20 cm (probably due to seedling irrigation). It is likely that run-on ditches contributed to evaporation through the side-walls of the ditches, resulting in the rapid moisture loss recorded during prolonged dry spells. Additionally, the run-on ditch bed had 60 to 90% vegetation cover during this time, resulting in significant moisture loss through transpiration, while the control bed had less than 10% cover. More detail about run-on ditch WUE efficiency and data analyses can be found in Sturdy *et al.*, in preparation.

3.6.4. Drip irrigation

Drip irrigation was found to be impractical in Potshini, as the available drip kits were prone to malfunction or break and farmers believed they did not provide enough water to the plants (compared to watering cans). In addition, drip kits and parts are not easily accessible in the Bergville district, which is very prohibitive for innovation dissemination. The drip kit trial prepared during this project yielded insufficient data for determining potential WUE because leakage from the drip line connections resulted in drip irrigation being used only minimally throughout the 9 month field study.

3.7. Pre-conditions and Pathways for Sustainable Innovation Adoption

Conditions found to affect sustainable adoption of innovations in Potshini are listed in Table 3. The ranking system used in this table was qualitatively constructed using information gathered through questionnaires, informal discussions and group matrix scoring. Not all of the conditions identified must be met to ensure adoption and dissemination of an innovation, but adoption will be more likely when more of the conditions are met.

Table 3
Ideal conditions required for successful and efficient adoption, adaptation and dissemination of agricultural innovations in Potshini.

Conditions for successful, sustainable adoption	Socio-economic (S) / Biophysical (B)	Qualitative importance ranking[a]
Income generation clearly exceeds cost of innovation upkeep	S	1
Does not conflict with cultural beliefs/practices	S	1
Markets established (if innovation increases yield for commercial sale)	S	1
Business mentoring provided (if innovation increases yield for commercial sale)	S	1
Required inputs available & affordable	S	1
Increases long term income	S	2
Increases food availability	B, S	2
Increases skills & knowledge for making decisions	S	2
Low or no monetary start-up cost for farmer	S	2
Local example(s) of innovation's success/benefits	S, B	2
Trainable (not complex in terms of scheduling, understanding process, etc.)	S	2
Conserves water	B	3
Minimizes daily manual labour	S	3
Improves grazing / livestock health	B, S	4
Fosters family cooperation	S	4
Conserves soil	B	4
Makes use of &/or strengthens social networks/cohesion	S	4

[a] 1 = Critical, 2 = Very Important, 3 = Important, 4 = Beneficial but not required

Once innovation types have been agreed upon, the pathways for facilitation can be constructed, again with input from community members. Pathways and their effectiveness, as observed in Potshini, are listed in Table 4. One of the more successful pathways observed, in terms of the number of farmers who adopted introduced innovations and continued to use them the following year, was a series of hands-on gardening workshops (FLWs), conducted at different farmers' homesteads on a monthly basis, and open to the entire community. Surveys and informal discussions conducted during this study, along with two surveys (n=19 and n=27) conducted four to six months after FLWs ended indicated that at least 91% of workshop participants were still gardening and that the majority of introduced gardening practices were in use by 26 to 79% of participants, depending on need and required inputs, with some innovations such as trench beds and organic pest control being favoured over others (Mudhara *et al.*, in review; RIE, 2008). It is likely that spreading the workshops over several months played an important role in sustained adoption of gardening practices as it allowed farmers to experiment with innovations between workshops, review and repeat training content as needed and share feedback with the group. Workshops with similar content completed over a 3 to 5 day period have proven to have far less, if any, impact in other smallholder farming communities in South Africa (Kruger, 2008). The hands-on nature of the workshops, along with the rotation of workshop presentation from one homestead to another also appeared to positively impact farmer understanding and motivation. While knowledge sharing within an organized group tended to be useful and motivating for farmers, it should also be noted that the learning, work and progress of individuals within the FLW group did not depend on participation of other group members. Informal discussions with farmer leaders in Potshini indicated that working groups in which livelihood improvement for individuals is dependent on the participation of each member tend to fall apart before reaching a sustainable level.

Table 4
Observed pathways for facilitating adoption and dissemination of innovations in Potshini (Observed Effectiveness Rankings: 1=very successful, 2=moderately successful, 3=not very successful).

Pathway	Observed Effectiveness Rankings for: ADOPTION	DISSEMINA-TION	understanding & successful long term use of innovation
Series (5 or more) of monthly, HANDS-ON training workshops	1	1	2
Training motivated leader farmers	1	2	2
Facilitating individual farmer experimentation	1 - 2 [a]	2	1
Knowledge sharing through local groups/coops	2	1	2
Researcher visits to homesteads	1 - 2 [a]	2	2
Cross-visits to other farming communities	1 - 2 [b]	2	3 [b]
Provided incentives &/or start-up materials	1	3	3
Classroom training - group problem solving exercises	2	2	2
Demonstrations	2	2	2
Radio/TV broadcasts	2	3	3
Printed materials (pictures & diagrams)	2 - 3 [c]	2 - 3 [c]	2 - 3 [c]
Mother/Baby technology trials	2 - 3 [d]	2 - 3 [d]	2 - 3 [d]
Printed materials (text)	3	3	3
Classroom training - lectures	3	3	3

[a] effectiveness of pathways that involve working with individual farmers varies according to the socio-economic situation and personal motivation of the farmer.
[b] cross visits are good motivators and can be a very effective pathway for adoption and understanding when combined with training on innovations observed during visits.
[c] dependant on purpose, content and distribution
[d] could have been more effective if technologies focused more on cost-benefit for farmers

Intensive facilitation of farmer-driven experimentation, as was implemented through the case study process during this project, proved to be valuable in terms of cultivating a strong understanding (for both researchers and farmers) of innovations and their potential value for the individual homesteads involved, some of which were able to provide assistance and knowledge to other farmers in the community. These farmers became more proficient with gardening in general through comparing innovations and making decisions based on observations. One year after facilitation had ended, all of the participating homesteads continued to cultivate large (10 m^2 or larger), diverse gardens and at least two of the six continued to plan and execute garden experiments comparing different practices. However, knowledge sharing outside of the FLWs occurred only minimally during the life of the project, so this facilitation process was not as successful at disseminating innovations as the workshop process. It is likely that a combination of the pathways presented in Table 4 will be more successful for sustainable, widespread dissemination than a single pathway, and that differing levels of complexity for various innovations will require different pathway combinations.

4. Conclusions and Recommendations

Identifying and working with existing platforms and processes, such as extension officers, researchers, NGOs, local co-ops and farmer forums, can be a time consuming but critical avenue for building an understanding of community assets, vulnerability, essential livelihood activities and perceived risks. These dynamics explain much of the innovation adoption process, as they encompass both biophysical and socio-economic factors that influence farmers' decisions about adopting new technologies. Although building relationships with stakeholders in Potshini required a significant amount of time and effort initially, the result was a more efficiently designed project that took into account the innovations farmers were already familiar with and interested in, thereby directing research toward addressing needs and priorities of community members.

It is not adequate to promote innovations that scientific research has shown can improve crop yields or water conservation under given biophysical conditions without addressing the socio-economic aspects of farmers' decision making. Innovation selection should involve farmers' opinions and perceptions at the onset of the project, as should the process of choosing facilitation pathways. Various PLA techniques can be used with small groups of farmers to involve them in the process of choosing innovations to introduce to a community. Farmers may not be aware of nor understand the function of the differing innovative options, but they do know their own livelihood priorities and can help researchers identify the conditions that must be met for an innovation to be successfully adopted.

In Potshini, and in other subsistence farming communities in Southern Africa, hands-on, monthly workshops that focus on problems identified by the farmers themselves can be a successful pathway for facilitating adoption. Group workshops provide a venue for farmers to share concerns and knowledge, which is an important avenue for innovation dissemination because farmers tend to adopt innovations that have been tried and introduced to them by other farmers. Through such workshops, farmer leaders can be identified and motivated farmers can be chosen for individualized training or farmer experimentation, which have been successful pathways for fostering thorough understanding of innovations. Experimentation allows farmers to assess the value of innovations they choose to study while improving their ability to make informed decisions through critical thinking and analysis, particularly when farmers own innovative abilities are respected and encouraged. It also develops their confidence in explaining the function of innovations to others. In addition, farmer-driven experimentation can provide valuable data for researchers' studies into the biophysical aspects of innovations.

Gardens provide a small-scale, low-risk learning environment for experimentation through trial comparisons. Problem solving skills developed during garden trials can be extended to other aspects of rural life and agriculture. Additionally, gardens did have an obvious positive effect on the livelihoods of at least half of the farmers participating directly in this study by providing a continuous supply of diversified vegetable nutrients to the diet, saving money otherwise spent on vegetables or by providing income though selling produce to neighbours.

In a community where gardening is not common practice, introducing innovations involving garden layout, bed design, soil treatment, pest management and other methods needed to initiate a healthy garden environment is a logical starting point. Many such innovations can help optimize WUE, yet to *maximize* WUE, irrigation practices must be adjusted to suit the given environment. During the course of this 9 month field study, irrigation practices changed only marginally in Potshini. Additional time must be spent evaluating irrigation strategies and analysing water balance information with farmers in order to significantly change practices. Structured experiments to compare irrigating often with shallow infiltration to irrigating less often with deeper infiltration could be managed by farmers (*e.g.* 3mm daily vs. 20mm once a week), as could comparisons of drip, flood and bucket irrigation. Monitoring rooting depths for the different irrigation schedules could be a practical, farmer-determined indicator for WUE as it relates to plant health.

Technical tools, such as Wetting Front Detectors, that farmers can use themselves to assess the value of different innovations can be useful, but to realize their full potential, time and energy must be spent on learning (and hands-on teaching) how information provided by these tools can be used to adjust gardening or farming practices. It should not be assumed that because a farmer knows how a tool operates that they also know how to affectively apply information provided by that tool. Even after overcoming this and other limitations, such as lack of availability, tools like the WFDs will only be useful to a certain percentage of farmers because the farmers who are not interested in keeping records or in refining their practices, usually due to more pressing livelihood activities or interests, will not take the time to evaluate WFD generated information, nor risk modification of their own practices accordingly.

Drip irrigation may have potential in Potshini and other South African subsistence farming communities, but not until drip kits and parts are easier to acquire and less prone to breaking and leakage. Additional research on WUE involving farmer experimentation with variable irrigation amounts and timing is needed to realize the potential benefits of drip irrigation in rural South Africa.

Trench beds can be an effective, inexpensive organic method of decreasing acidity while increasing phosphorus in the rooting zone. Both trench beds and run-on ditches appear to retain moisture fairly well compared to traditional beds during consistent rains and short dry spells. Additional research to determine optimal trench bed and run-on ditch designs would be valuable to farmers as it would allow them to refine designs to maximize WUE and production within the context of their individual climatic, economic and soil constraints. Research spanning the dry season as well as additional rainy season research would be valuable for both farmers and researchers in terms of understanding the strengths and limitations of these innovations, as would additional repetitions of the same experiments with an emphasis on reducing variables such as crop cover.

Promoting sustainable adoption and dissemination of innovations requires an iterative learning process that involves participation, feedback and adaptation by community members. The integrated, participatory method of data collection and learning employed during this project required more time than a less holistic process might, but it resulted in a better understanding of the practical value of innovations than a purely technical approach. It allowed researchers to build an understanding of socio-economic influences as well as biophysical factors affecting adoption of innovations, while at the same time producing biophysical data capable of delineating the value of innovations within the given environmental context.

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References

Abadi Ghadim, A.K., 2000. Risk, Uncertainty and Learning in Farmer Adoption of a Crop Innovation. Unpublished PhD Thesis, Faculty of Agriculture, University of Western Australia, Nedlands, Western Australia.

Bengesi, C.P.M., Wambula, R.M. and Ndunguru, P.C., 2004. Farmers' utilization of agricultural innovation: A case study of adoption of hybrid production technologies in Mwanga District, Tanzania. *Uongozi journal of management development* Vol.16 (2) 133-143.

Hocdé, H., 1997. Crazy but not mad. *In*: Veldhuizen, L.V., Waters-Bayer , A., Ramirez, J.R. , Johnson, D. , Thompson, J. (Eds.), Farmers' Research in Practice: Lessons from the Field. Intermediate Technology Publications, pp. 49-60.

Holst, M., 2007. Personal communication. World Vision Project Manager, Bergville, RSA, January 2007.

Kosgei, J.R., Jewitt, G. 2006. Realizing Food Security in Semi-Arid Agro-ecosystems of Southern Africa: Does the Potential Lie in Upgrading Rainfed Agriculture? Proceedings of the 10th Annual Searnet conference, 4th-6th December 2006; Mombasa, Kenya.

Kruger, E. 2006. How to use or to improve current/indigenous practices or systems. Internal report for Water Research Commission Project K5/1575/4 - Participatory Development of Training Material for Agricultural Water Use in Homestead Farming Systems for Improved

Livelihoods. Compiled by Rural Integrated Engineering (Pty)Ltd., Pretoria, RSA. September 2006.
Kruger, E. 2007. Personal communication. Independent Development Practitioner. Peitermaritzburg, RSA, 17 January 2007.
Kruger, E. 2008. Personal communication. Independent Development Practitioner. Peitermaritzburg, RSA, 18 March 2008.
Liniger, H. and Critchley, W., 2007. Where the Land is Greener: Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide. World Overview of Conservation Approaches and Technologies (WOCAT), Bern.
Marra, M., Pannell, D.J., Amir, A.G., 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems* 75 (2003) 215–234.
Meinzen-Dick, R., Adato, M., Haddad, L., and Hazell, P., 2003. Impacts of Agricultural Research on Poverty: Findings of an Integrated Economic and Social Analysis. Environment and Production Technology Division, Food Consumption and Nutrition Division, International Food Policy Research Institute, Washington, D.C., U.S.A. Available from http://www.ifpri.org/divs/eptd/dp/papers/eptdp111.pdf. [Accessed 27 June 2007].
Mudhara, M., Malinga, M. and Salomon, M., in review. Enhancing farmers innovative capacity in soil and water management through participatory action research in Potshini, South Africa. *Physics and Chemistry of the Earth.*
Ngigi, S.N., Savenije, H.H.G., Rockström, J. and Gachene, C.K., 2005. Hydro-economic evaluation of rainwater harvesting and management technologies: Farmers' investment options and risks in semi-arid Laikipia district of Kenya. *Physics and Chemistry of the Earth* 30:772-782.
Okhahlamba Local Municipality, 2007. Draft IDP 2006/07 Review. Bergville, RSA.
Rural Integrated Engineering (Pty) Ltd. (RIE), 2008. Concept Note for intensive food production at homestead level. Refinement Report 2007/2008 for Water Research Commission Project: K5/1575/4 - Participatory Development of Training Material for Agricultural Water Use in Homestead Farming Systems for Improved Livelihoods. Pretoria, RSA.
Rockström, J. 2000. Water resources management in smallholder farms in eastern and southern Africa: an overview. *Physics and Chemistry of the Earth* (B) 25 (3):275–283.
Rockström, J. 2003. Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth* 28 (20-27):869-877.
Shahvali, M., Zarafshani, K., 2002. Using PRA techniques as metacognitive strategies to develop indigenous knowledge – a case study. UNESCO ISSI 173/2002. Blackwell Publishers, Oxford, UK. Available from: http://www.blackwell-synergy.com/doi/pdf/10.1111/1468-2451.00393. [Accessed 3 May 2007].
Smith, HJ, Trytsman, G, Bloem, JF, Everson, T, and Mthethwa, S. 2005. Development and Implementation of Sustainable Land Management Practices in the Bergville District of the KwaZulu-Natal Province. ARC-ISCW Report Number GW/A/2005/04. Fourth Progress Report to the KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara, RSA.
Snapp, S., 1999. Mother and baby trials: a novel trial design being tried out in Malawi. *In* TARGET. The Newsletter of the Soil Fertility Research Network for Maize-Based Cropping Systems in Malawi and Zimbabwe. January 1999 issue. CIMMYT, Zimbabwe.
Statistics South Africa, 2001. Census 2001, interactive and electronic database. Available from: http://www.statssa.gov.za/census01/HTML/C2001Interactive.asp. [Accessed 20 February 2007].
Stirzaker, R., Stevens, J., Annandale, J., Maeko, T., Steyn, M., Mpandeli, S., Maurobane, W., Nkgapele, J., and Jovanovic, N., 2004. Building Capacity in Irrigation Management with Wetting Front Detectors. Water Research Commission. WRC Report No. TT 230/04. Gezina, RSA.
Sturdy, J.D., Jewitt, G.P.W., Lorentz, S.A., in preparation. Participatory evaluation of soil water movement with differing garden bed designs and irrigation practices. Chapter 3,

MSc thesis, School of Bio-resources Engineering & Environmental Hydrology, University of Kwa-Zulu Natal, Scottsville, South Africa.

Quinn, C.H., Huby, M., Kiwasila, H., Lovett, J.C., 2003. Local perceptions of risk to livelihood in semi-arid Tanzania. *Journal of Environmental Management* 68, 111-119.

United States Environmental Protection Agency (EPA), 2000. Commentary resulting from a Workshop on the Diffusion and Adoption of Innovations in Environmental Protection. A Commentary by the EPA Science Advisory Board (1400) A, Washington D.C., EPA-SAB-EEC-COM-01-001. Available from: http://www.epa.gov/sab/pdf/eecm0101.pdf. [Accessed 27 June 2007].

Vanclay, F. and Lawrence, G., 1994. Farmer Rationality and the Adoption of Environmentally Sound Practices; A Critique of the Assumptions of Traditional Agricultural Extension. *The European Journal of Agricultural Education and Extension* 1(1):59-90.

World Vision South Africa, 2006. Baseline Survey Report: Okhahlamba Area Development Programme. Project Number 173116. World Vision South Africa National Office, Johannesburg, RSA.

World Vision, Inc., 2003. Final Evaluation Report. Thukela District Child Survival Project, HIV/MED Grant Amendment. Submitted to Child Survival Grants Program USAID/BHR/PVC, Washington, DC.

CHAPTER THREE

Second Publishable Paper

Participatory evaluation of soil water movement with differing garden bed designs and irrigation practices

For Submission to Water South Africa

Participatory evaluation of soil water movement with differing garden bed designs and irrigation practices

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ABSTRACT

In South African regions prone to drought or dry spells, the inherent risks involved in subsistence agriculture can be acute. In these areas, biophysical constraints intensify the challenge of securing a livelihood amidst the backdrop of existing socio-economic norms and constraints. Within this context, it is the farmers' perceptions of needs, investment options and risks that drive their decision making process and hence the adoption (or non-adoption) of introduced innovations. In the Potshini village in rural KwaZulu-Natal, participatory research involving facilitation of farmer-driven experimentation allowed farmers to methodically assess the value of innovations they chose to study while providing researchers with valuable feedback and data concerning the function and reliability of innovations under specific biophysical and socio-economic conditions. During this study, observations and data collected manually by farmers were used to supplement laboratory generated and electronically recorded information about soil water dynamics associated with different garden bed designs and irrigation methods. Compared to traditionally prepared control beds, trench bed samples showed decreased acidity and increased phosphorus in the rooting zone. In addition, trench beds appeared to retain more moisture throughout the soil profile than control beds during wetter months, including short dry spells spanning up to 6 days. However, gradual but consistent increases in soil water tension were recorded in trench bed soils during prolonged dry spells, possibly as a result of high connectivity between pore spaces in the trench beds, combined with evapotranspiration associated with vegetation cover. Water harvesting with run-on ditches resulted in greater water infiltration to depths of 80 cm than was shown in an 80 cm control bed during consistent rains. However, during a series of prolonged (8 to 12 day) dry spells, soil in the run-on ditch bed began to lose moisture significantly at all depths, while soils in the control beds also lost moisture but at a more gradual rate. This may have been a result of evapotranspiration at the run-on ditch bed associated with heavy vegetation cover as well as evaporation through the 20 cm deep ditch sidewalls surrounding the bed. Drip irrigation was found to be impractical because the available drip kits were prone to malfunction and farmers believed they did not provide enough water to the plants. Wetting Front Detectors (WFDs) were shown to have some potential as management tools for farmers, provided certain limitations such as availability and sun sensitivity are addressed. To fully realize the potential of WFDs in subsistence gardening and farming, farmers and researchers need to engage in discussions and demonstrations or experiments related to the movement of water within the soil profile, such as rooting depth and it's relation to "wetting fronts" and their significance in terms of plant production.

Keywords: Innovation adoption; Participatory research; Smallholder farmers; Subsistence gardening; Trench beds; Water harvesting; Wetting Front Detector

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1. INTRODUCTION

When agriculture is constrained by poor rainfall distribution and partitioning, innovations that increase rainwater use efficiency, often involving rainwater harvesting and related management strategies, have significant potential for improving livelihoods and increasing food security (Rockström, 2000; Rockström, 2003; Ngigi *et al*., 2005). In subsistence gardens, such innovations may focus on the conservation of soil water, which has been shown to increase crop yield and minimise the labour effort of the farmer. However, investing in agricultural innovations is inherently risky, particularly in regions prone to drought or dry-spells (Ngigi, 2005). For farmers to decide that an innovation is worthy of investment, they should have a realistic understanding of its risks and benefits, including factors such as time and monetary input requirements, as well as potential effects on yield and soil and water conservation. This reduces the risk of wasting resources on an innovation that is not suited to their specific situation, which could lead to reluctance towards trying other potentially beneficial innovations.

Facilitation of farmer-driven experimentation allows researchers to build an understanding of the factors influencing farmers' decision making processes and can provide valuable data and observations they would not otherwise be able to collect. At the same time it gives farmers an opportunity to aid in the development and adaptation of innovations that are relevant to their own biophysical and socio-economic situation. Through this process farmers can gain insight into the value of different innovations while developing their own methodology for experimenting with new ideas and comparing them to traditional practices. Additionally, strengthening critical thinking skills through experimentation has the potential to contribute to long term well being through increasing a farmer's self confidence and ability to adapt to a changing environment (Sturdy *et al*., 2008).

The aim of this study was to assess socio-economic conditions required for adoption and dissemination of innovations in a subsistence farming community while fostering farmers' problem solving abilities and investigating the biophysical aspects of garden scale water use innovations. To meet this aim, farmer-led garden experiments were facilitated using Participatory Learning and Action (PLA) research methods within a South African subsistence farming community. Results of socio-economic assessments are discussed in Sturdy *et al.*, 2008, while this paper focuses on the methodology and results of biophysical investigations into soil water movement associated with differing garden bed design and water application innovations.

In this study, a focus at garden scale provided a means for evaluating innovations and developing farmers' experimentation skills in a less risky environment than working at a larger agricultural scale might have, although the methodology and tools employed by farmers are also applicable to agricultural innovation development. Tools such as manual rain gauges and Wetting Front Detectors (WFDs) are well suited for participatory research as they can provide farmers with valuable insight into their own agricultural and gardening practices. They can also provide researchers with useful data that could not be recorded without the collaboration of farmers. In this study these tools, along with other technical and electronic instruments, were used to collaboratively evaluate irrigation practices (drip and run-on irrigation) and bed design (trench beds and run-on ditches) in terms of situational relevance and availability of water to the plant.

This study took place over a single growing season (September to April 2006-7) and forms part of the Smallholder Systems Innovations (SSI) project, a research initiative aimed at assessing the potential agrohydrological and social impact of water related innovations based in Potshini, a rural subsistence farming community in the Okhahlamba Municipality of the Bergville district in South Africa (Figure 3.1). Potshini consists of about 400 homesteads and covers an area of approximately 2.5 km^2. Precipitation falls primarily during summer months, from September to May and mean annual precipitation is estimated at approximately 700 mm/year. Strong, dry winds are experienced in August and September. Several boreholes with hand pumps provide water for domestic use, in addition to small streams that also replenish reservoirs for downstream commercial farmers. Water is pumped and carried to the homesteads by hand using 20 litre containers. Winters are cold and frost is common from early May to late August with occasional snow and extremely low stream flows. Some farmers in the community would like to grow vegetables during the winter months, but the lack of water availability, the possible frosts and the presence of livestock during the winter months has been prohibitive.

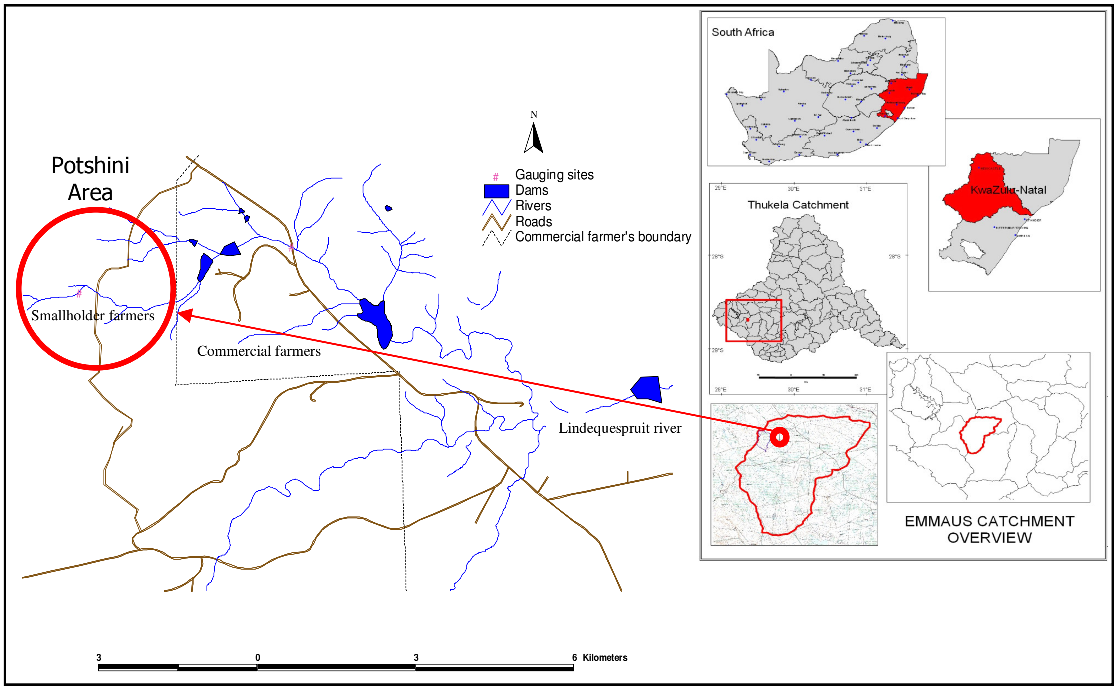


FIGURE 3.1. Location of study area in the Bergville District, South Africa (after Kosgei and Jewitt, 2006).

2. RESEARCH METHODOLOGY

Several Participatory Learning and Action research techniques were implemented during this study in order to collect information about biophysical constraints on local gardening and agriculture, as well as farmers' perceptions and decision making processes. In addition, various sets of technical soil water monitoring equipment were installed in some of the gardens, as described in the following section. Due to financial and other constraints, the study reported herein was limited to a single growing season and a single follow-up visit one year later.

2.1 Soil Moisture Monitoring and Characterisation

In order to assess the effect of different innovations on crop water availability, a range of instruments designed to acquire information relating to water balance components were placed in the gardens of the six participating farmers. These complemented a detailed Potshini Catchment monitoring network which also provided supplemental data where necessary (Kongo *et al.*, 2006). The instruments installed included manual reading rain gauges, Wetting Front Detectors (WFDs), nested Watermark® sensors (WMS), and Capacitance Probe tubes. Descriptions of each instrument's function are presented in Table 3.1 and a diagram showing instrument configuration is presented in Figure 3.2. An explanation of the innovations chosen by farmers for comparison to a control and the instrumentation used for individual trials is presented in section 2.3.

TABLE 3.1
Description of technical instrumentation function.

INSTRUMENT	FUNCTION	Monitoring Strategy
Manual Rain Gauge	Used to measure rainfall (mm).	Monitored daily by farmers.
WFD	Provides visual signal when "wetting front" has reached a certain depth. Works on the principle of flow line convergence. Water moving from surface downwards through soil is concentrated when water molecules enter the wide end of WFD funnel. Soil in funnel becomes wetter as funnel narrows. Funnel shape is designed such that soil at the base of the funnel's bowl reaches saturation when wetting front outside funnel is at a similar depth. After saturation, free water flows through a sand filter into a reservoir where a float is activated, causing a plastic indicator to pop up above ground. As wetting front dissipates, water is withdrawn from the funnel through capillary action. WFDs are placed as a pair, one about half way down the managed root zone and a deeper one near the bottom of the managed root zone (Stirzaker *et al.*, 2004).	Recorded by farmers when activated by rainfall or irrigation.
WMS	WMSs measure water tension in the soil, which increases with decreasing water content. WMSs consist of a fine aggregate mixed with a gypsum buffer, held inside a permeable membrane and a perforated stainless steel sleeve. The sensors are buried in contact with the soil and attain equilibrium with the soil moisture. Electrodes are embedded in the aggregate/gypsum matrix and the electrical resistance between them is measured to determine soil moisture. The varied resistance is calibrated against known values and reported in terms of soil water tension. Resistance decreases with decreasing soil moisture. Signal may fluctuate with soil temperature changes (Irrometer Co., 2006).	Electronically recorded every 30 Minutes. Data downloaded for post processing by researcher every 4 weeks.
Capacitance Probe	The Capacitance Probe measures near surface changes in soil water content. It functions by lowering the probe to certain soil depths through a tube, and sending very high frequency (~GHz) electrical signals into the soil. The reflected signal is a function of soil water content. Facilitates water content profiling by recording water content information from multiple depths (Wallace, 1996).	Weekly recording at depths 15, 30, 45, 60 and 75 cm undertaken by researcher and local field assistant.

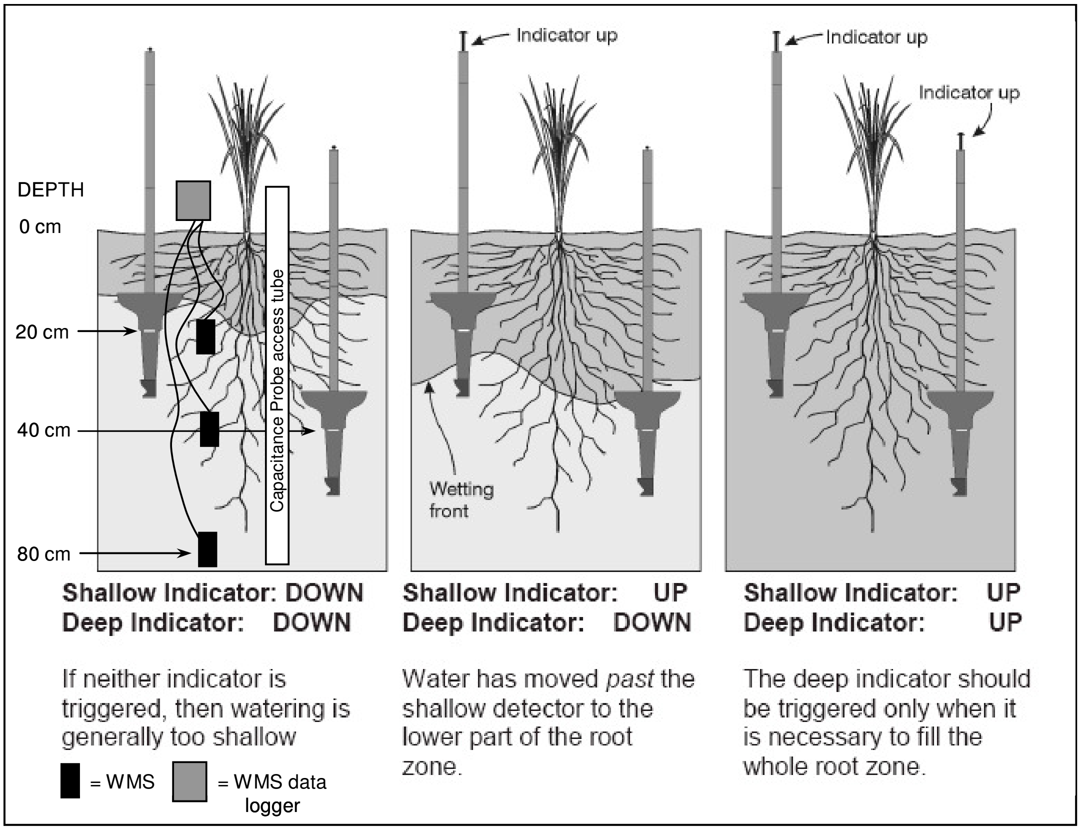


FIGURE 3.2: Idealized diagram of Wetting Front Detector activation process (altered from Stirzaker *et al.*, 2004). Idealized placement of Watermark® sensors and Capacitance Probe access tube shown in far left diagram. Soil temperature sensor at 20 cm depth not shown. Drawing not to scale.

The WFD is a mechanical instrument which activates a pop-up signal when water in the form of a "wetting front" resulting from rainfall or irrigation passes a certain depth, as illustrated in Figure 3.2 (Stirzaker *et al.*, 2004). WFDs can be useful in terms of participatory learning because they are a technical tool that is not electronic and they provide an immediate visual signal, allowing farmers to see when the soil has become saturated to certain depths. Ideally this knowledge can be used to adjust irrigation amounts and timing to maximize Water Use Efficiency by determining the amount of water required to reach rooting depth without infiltrating beyond depths accessible to crop roots. The WFD can also be used to monitor solutes and nitrates in irrigation water at specified depths, which can indicate consistent under irrigation (resulting in saline water) or over irrigation, indicated by dramatic changes in nitrate concentration (Stirzaker *et al.*, 2007). However, WFD data collection in this study focused solely on WFD activation events and irrigation water sampling was not incorporated into the learning process.

While the WFD was originally developed as an irrigation control tool, a Water Research Commission project using participatory research showed that its primary value was the role it played as a learning tool (Stirzaker *et al.*, 2004). Stirzaker *et al*. (2004) reported that by treating the instruments as learning tools, WFDs were successfully used to create a dialogue between farmers and researchers, challenge the perceptions of both parties and stimulate changes in irrigation practices. During that study, WFDs did not answer all of the farmers' questions, but they helped them formulate their next set of questions. Changes reported by farmers included irrigation timing as well as the quantity of water applied. In some instances farmers' acceptance of the WFD as a valid decision support aid in irrigation management required three years of experimentation, while other farmers used the WFDs to change their practices soon after their introduction. Stirzaker *et al*. (2004) concluded that on-going support in the use of WFDs is important for ensuring that the technology not be discontinued after its introduction. This is especially true when working with small scale farmers because substantial input is required for them to acquire skills needed to make effective use of the WFD

WMSs, used to measure soil water tension, and the Capacitance Probe, which measures water content, provide digital signals in response to different soil water characteristics at different depths which can be stored with electronic data loggers. Data collected with the Capacitance Probe was incomplete due to equipment malfunction throughout the season, and was not used for detailed data interpretations. Information from technical tools was supplemented with laboratory generated soil analyses (hydraulic conductivity and nutrient analyses) and in-field soil hydraulic characterizations (double ring and tension disc infiltrometer tests, Lorentz *et al., 2001*) in two of the six gardens. Curves were fitted to hydraulic characterization data using the van Genuchten equation and used to strengthen interpretations of soil water tension data.

2.2 Participatory Processes

As part of the participatory process, SSI researchers facilitated a series of Farmer Learning Workshops that were organized in conjunction with a development initiative sponsored by the South Africa's Water Research Commission (WRC) to design training materials for efficient water use in homestead farming systems (Rural Integrated Engineering (Pty) Ltd., 2008). A total of 9 workshops were held in Potshini on a monthly basis, each time at a different farmer's homestead. These focused on a variety of organic gardening practices (including pest control, tower gardens, mulching, bed design, water harvesting, irrigation, etc.), encouraged farmer-driven experimentation and included group assessments of each others progress and reviews of previous workshop content. In parallel with the workshops, two Farmer Learning Groups were established, each with a leader farmer elected by group members. Leaders assisted with workshop organization and communicated group questions and goals to WRC and SSI facilitators. They also assisted group members with understanding and implementing introduced innovations. These workshops were essential in that they introduced many farmers to a number of gardening innovations that could be experimented with in homestead gardens and provided a venue for sharing observations about innovations with researchers and other group members.

Other participatory techniques used included case studies, informal discussions, work sharing, villager presentations, process notes, personal diaries, semi-structured interviews, key informants and matrix scoring (Sturdy, *et al.*, 2008). The majority of time spent on participatory processes involved case studies that focused on six farmers who were invited to participate in facilitated experimentation. Both the Farmer Learning Groups and the facilitated experimentation case studies focused on the four phases of Action Research: act, observe, reflect and modify (Herr and Anderson, 2005). This was accomplished by encouraging farmers to try innovations in their gardens, observe and record the effectiveness of the innovations, reflect on the value of each innovation (as an individual and as a group) and modify their garden plan by either altering the original innovation(s) or abandoning the innovation and choosing different innovations to experiment with.

The six farmers participating in case studies were provided with rain gauges and encouraged to conduct their own experiments by comparing traditional planting techniques to new gardening methods and ideas, but only three of the six gardens were outfitted with a full suite of technical instruments (as described below). Farmers were willing and eager to try using WFDs and rain gauges and to have technical instrumentation placed in their gardens. They were not sure how the instruments might improve their gardening or irrigation at the onset of the project, but there was no risk involved in placing the instruments so none of the farmers were averse to the idea of “trying them out”. The original six farmers were chosen with an effort to work with people from diverse backgrounds and gender (3 men and 3 women), however, of these the three whose gardens were selected for technical experimentation were based on expressed willingness and level of literacy (required for taking notes and keeping records). Facilitation visits were made to homestead gardens two to four times per month during the 2006-2007 growing season. Farmers were involved in placement of the WFDs and were shown how the instruments are activated. They were then asked to record each WFD activation event, along with irrigation timing and amounts and daily rain gauge data on provided forms. At this stage some risk was introduced to the process because daily data collection requires valuable time that might be spent on other livelihood activities. After the first month it became clear that two of the three farmers would keep reliable daily records, while the third farmer was less interested in working in her garden in general and would only occasionally record observations.

2.3 Garden Bed Design and Sampling

Although a number of gardening innovations were suggested, research trials were designed, as much as possible, around the interests of the farmers, who chose which innovations they would experiment with (Sturdy *et al*., 2008). Trials chosen by farmers for experimentation compared traditional techniques to garden bed designs and irrigation technologies recently introduced through Farmer Learning Workshops. Thus, the study included:

1. “Traditional” garden bed design and preparation (bed “turned” with hoe and fork and fertilised in some cases), irrigated by hand watering only, used as the “control” bed at each location.
2. Trench beds, constructed by digging a 60 cm pit and filling it with consecutive, 5 cm thick layers of local grass, manure and soil (Figures 3.3 and 3.4).
3. Manually constructed, 20 cm deep run-on ditches, designed to direct local rainwater runoff into the garden and around the beds using gravity and a network of level trenches with check-dams and overflow outlets (Figure 3.5).
4. A drip irrigation kit, used to conserve water by irrigating directly at the base of individual plants with a slow drip from a network of plastic pipes (Figure 3.6). A summary of farmer-selected technical experiments is presented in Table 3.2.

FIGURE 3.3: Site K3tb, November 2006. Completed trench bed (left) shown alongside pit waiting for trench bed fill material (layers of grass, soil and manure). Traditional garden beds used for experiment control can be seen surrounding the trench bed. Bed surface dimensions are 90 cm x 150 cm, depth is 50 cm.

FIGURE 3.4: Placing trench bed fill.

FIGURE 3.5: Site D3d, November 2006. Recently constructed, 20 cm deep run-on ditches surrounding garden bed. Bed surface dimensions are 90 cm x 400 cm.

FIGURE 3.6: Site S2tb (right, 260 cm x 110 cm by 60 cm depth) and S1n (left, 260 cm x 130 cm), November 2006. Drip irrigation system installation over control bed and trench bed.

TABLE 3.2
Summary of technical garden experiments and site ID's

Farmer	Innovation (site ID)	Control (site ID)	Technical Equipment Required
B	60 cm trench bed	traditional planting	1 rain gauge
U	60 cm trench bed	traditional planting	1 rain gauge
N	25 cm trench bed	traditional planting	1 rain gauge 2 pairs of WFDs
K	60 cm trench bed (K3tb)	traditional planting (K4n)	1 rain gauge 2 pairs of WFDs 2 nests of 3 WMSs 2 Capacitance tubes
D	ditch system for run-on distribution (D3d)	traditional planting (D2n)	1 rain gauge 2 pairs of WFDs 2 nests of 3 WMSs 2 Capacitance tubes
S	60 cm trench bed under drip irrigation (S2tb)	traditional planting under drip irrigation (S1n)	1 rain gauge 2 pairs of WFDs 2 nests of 3 WMSs 2 Capacitance tubes

At each of the four sites, the preparation of the control bed consisted of a planting area level with the walking path, which often led to farmers or their children compacting the soil by walking within the bed itself. The top 10 to 15 cm of soil in Farmer S's and Farmer D's control beds was turned and mixed with cow manure before planting, while no manure was added to the soil at Farmer N's and Farmer K's control sites. Trench beds and run-on ditch beds were raised and had obvious walking paths around them, reducing the amount of trampling and compaction of the bed. Profiles of the various bed designs are shown in Figure 3.7. Soil samples were collected for nutrient analyses and laboratory infiltration analyses, as shown in Table 3.3.

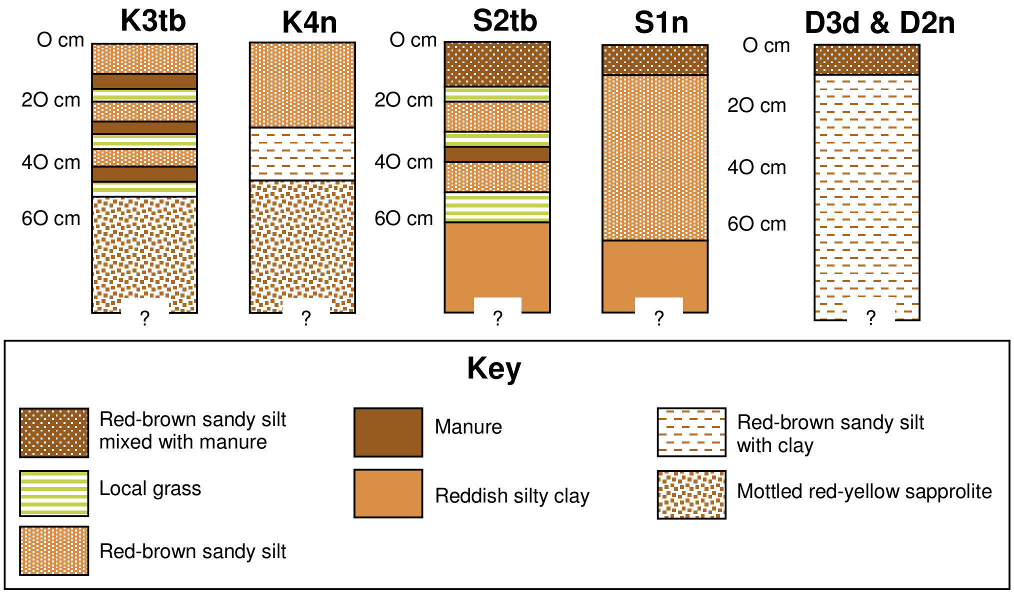


Figure 3.7: Soil profiles (classifications determined through field observations). D2n had a hard layer from 10-40 cm (possible plough-pan from hoeing in garden).

TABLE 3.3
Summary of soil sample depths, in-field soil hydraulic characterizations (double ring and tension disc infiltrometer tests for infiltration rates) and laboratory analyses (hydraulic conductivity and nutrients). Site ID's according to Table 3.2.

Site ID	Sample Depth (cm)	Lab Analyses and Field Characterizations
S2tb	0	nutrient, hydraulic conductivity, infiltration rate
	10	hydraulic conductivity, infiltration rate
	30	nutrient
	35	hydraulic conductivity, infiltration rate
S1n	0	nutrient, hydraulic conductivity, infiltration rate
	20	nutrient, hydraulic conductivity, infiltration rate
	53	nutrient, hydraulic conductivity, infiltration rate
	60	hydraulic conductivity, infiltration rate
D1n	0	nutrient, hydraulic conductivity, infiltration rate
	23	hydraulic conductivity, infiltration rate
	50	nutrient, hydraulic conductivity, infiltration rate
K1t	0	nutrient, hydraulic conductivity, infiltration rate
	10	hydraulic conductivity, infiltration rate
	35	hydraulic conductivity, infiltration rate
K2n	0	nutrient, hydraulic conductivity, infiltration rate
	25	hydraulic conductivity, infiltration rate

As a result of the small sample size and the nature of working collaboratively in farmers' homesteads and encouraging farmers to drive the experimentation process themselves, trials were less controlled than they could have been under strictly designed research conditions. For example, the two trench bed trials were tested in different soil conditions that cannot be directly compared to each other, while only one run-on ditch trial was conducted. Additionally, the crop cover over experimental beds and control beds varied significantly because gardens were relatively small (due to lack of fencing material) and farmers preferred to plant when the seedlings and the bed were available rather than waiting to plant both experiment and control beds at the same time with the same number and type of seedlings. For this reason, the number and depth of soil samples were limited to avoid damaging the existing vegetables. However, if research was extended over more than one growing season with the same farmers, tighter control of variables could be achieved through improving farmers' understanding of the value of minimizing variables.

3. RESULTS AND EVALUATION OF COLLABORATIVELY GATHERED DATA

3.1 Trench beds

Farmers in Potshini observed that some trench beds are more productive than others in terms of vegetable size and quantity (note that these were general, visual observations that were not quantified). This is most likely due to differences in the methods of construction as well as the original soil composition. Trench beds that were not filled with water during construction tended to produce smaller, less healthy vegetables (including onions, spinach and especially carrots) than those that were. In addition, when organic matter such as grass was placed near the top of the trench, plants (especially spinach) tended to wilt more easily, possibly due to heat generated by decomposition near the surface of the trench. It is typical to wait two months or more before planting in a newly constructed bed to allow time for decomposition of fill material (Environmental and Development Agency Trust, 1995). However, subsistence gardens are often relatively small and it can be impractical to leave a bed empty for long periods. In most cases in Potshini it was found that vegetables planted immediately after building a trench bed grew well, but it is likely that certain construction methods (such as placing several centimetres of soil on the top of the bed, and/or pre-mixing fill materials, and filling the bed with water during construction) would provide preferable conditions for immediate planting.

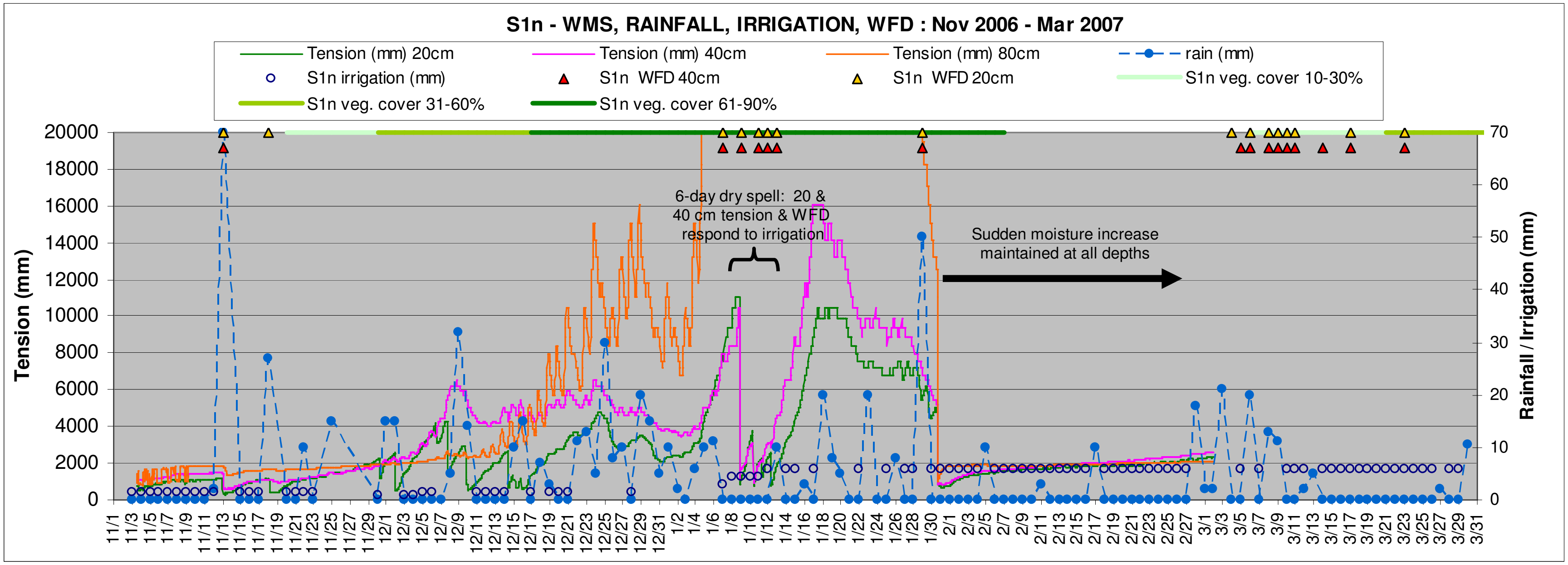
Highly acidic soils are common in the Potshini area and lime provided by the KwaZulu-Natal, provincial Department of Agriculture has been applied to many homestead fields, but gardens are typically too close to home structures to have been treated with lime. In Farmer S's garden the trench bed (S2tb) had no acid saturation with relatively neutral pH at the surface and at 30 cm depth (Table 3.4). The control bed (S1n) had fairly high acid saturation with low pH levels at 20 and 53 cm depth, while the surface sample was not highly acidic. The KwaZulu-Natal Department of Agriculture and Environmental Affairs' phosphorous recommendations for cabbage, carrot and spinach cultivation ranges from 27 to 120 mg/l. According to this recommendation, Table 3.4 shows that both samples from trench bed S2tb and the surface sample from control bed S1n contained adequate phosphorous, while phosphorous was low at 20 and 53 cm depth in the control bed. High acid saturation and low phosphorus was found at depth (50 cm) but not at the surface in Farmer D's garden control samples (D1n) as well. Soil samples were not taken at depth in Farmer K's garden and surface samples from both the trench bed (K1tb) and the control (K2n) had low acid saturation and sufficient phosphorus, though the trench bed had more than twice the phosphorus of the control bed. The lower acid saturation and higher phosphorus at the surface of control beds may be related to surface soil preparations such as mulch or dug in manure, while soil at depth in these beds had not been altered manually by the farmers. These results suggest that trench beds can be an effective, organic method of decreasing acidity while increasing phosphorus in the rooting zone.

TABLE 3.4
Soil nutrient analyses (March, 2007) from three vegetable farmers in Potshini, trench bed samples highlighted

Sample ID - depth (cm)	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Acid sat. %	pH (KCl)	Zn (mg/L)
S2tb - 30	72	595	1626	503	0	6.67	42.9
S2tb - 0	86	602	1563	535	0	5.49	26
S1n - 53	8	309	341	92	**22**	**4.29**	5.9
S1n - 20	8	484	482	149	**20**	**4.09**	9.4
S1n - 0	66	595	1392	428	0	6.41	37.9
D1n - 50	1	223	254	62	**30**	**4.26**	2.2
D1n - 0	23	323	946	126	1	4.99	13.5
K1tb - 0	98	470	829	221	1	4.87	12.1
K2n - 0	42	452	800	202	1	5	9.2

Data pertaining to water balances and Water Use Efficiency span only five months, from November 2006 to March 2007. Additional data collection and modelling (combining soil hydraulic characterization, soil water tension, irrigation and meteorologic data) is needed to construct a complete picture of hydrologic conditions and Water Use Efficiency within the studied gardens. However, available data are considered sufficient to compare movement of water within the trial beds to that in unmodified soil (control beds). Soil types differ notably between the two trench bed sites. Field observations identified Farmer K's unmodified soil as a red-brown *sandy silt* with increasing silt and clay content below 30 cm, underlain by a dense *sapprolite* at 45 cm depth, While Farmer S's unmodified soil is a red-brown *sandy silt* down to 65 cm, underlain by a reddish, *silty clay* (Figure 3.7).

WMS (soil water tension) data measured with the Watermark® Sensors from each trench bed trial site were compared to corresponding rain gauge, WFD and vegetation cover records in an attempt to understand the causes and relative rates of wetting and drying trends within soil profiles in both trench and control beds (Figures 3.8 and 3.9). As soil water tension increases, the amount of water within soil pore spaces decreases, i.e. the soil becomes drier. At Farmer S's site, water retention and hydraulic conductivity characteristic curves, shown in Figure 3.10, were determined for soils in the trench bed as well as the control bed. Hydraulic conductivity as well as water content were consistently lower in the control bed at all capillary pressure heads and at all depths than they were in the trench bed (refer to section 3.2 for a more detailed discussion of water content and hydraulic conductivity curves). Consistently low soil water tensions at 80 cm depth in the trench bed (S2tb) indicate that water contents were at the wet end of water retention characteristic curves throughout the study (suggesting more overall moisture retention) in the deeper end of the trench bed rooting zone than in the control bed (S1n), where tension fluctuated dramatically during the same period. Tension data indicates that the trench bed also retained more moisture in soils 20 and 40 cm deep than the control bed until early February, when an 11 day dry spell followed by a 10 day dry spell in the second half of February resulted in a notable drying trend at these depths in the trench bed. Near this same time, tensions dropped significantly in the control bed at all depths and remained stable through the end of February. The trench bed had 61-90% vegetation cover during this period, while the control bed had minimal cover from new seedlings, which would have resulting in the control bed being subject to less moisture loss through transpiration at that time. In both beds, soil water tensions at 20 cm depth were more responsive to rainfall and irrigation events than they were in deeper soils. During the dry spell spanning January 7th -12th, when both beds had 61-90% vegetation cover, moisture at 40 and 80 cm in the trench bed remained relatively high and stable, while tension records from 20 cm indicate drying followed by sharp increases in moisture in response to irrigation. During this same period, control bed tension records indicate extremely low moisture at 80 cm, and initial moisture loss at 20 and 40 cm followed by moisture increases with irrigation. WFD records indicate wetting fronts reaching 20 and 40 cm as a result of irrigation in the control bed during this period as well (no WFD data are available for the trench bed).



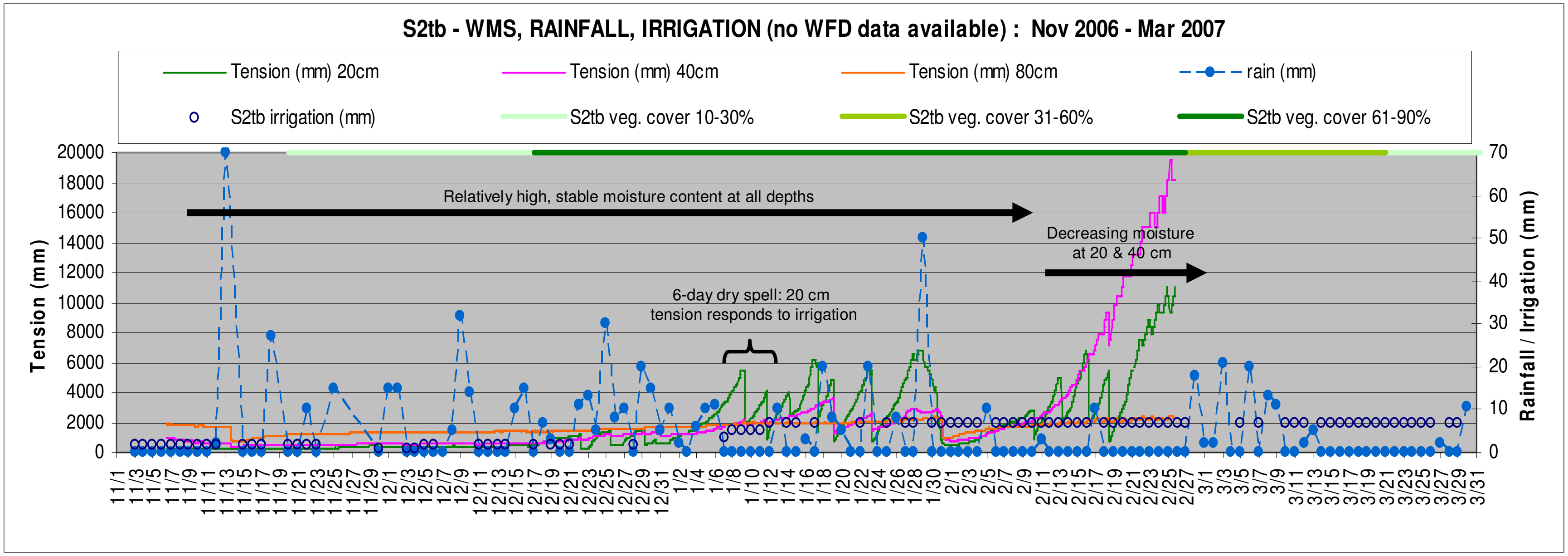
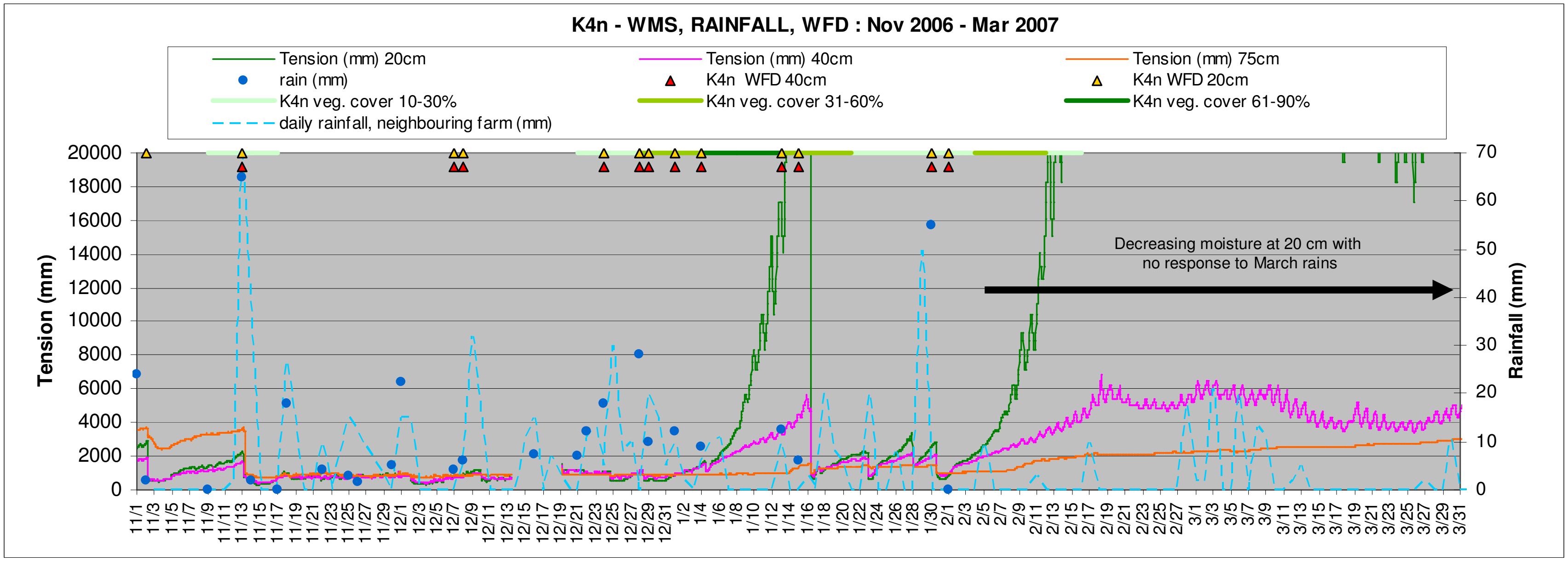


Figure 3.8: Farmer S's garden bed records: soil water tension, rainfall, irrigation, WFD and vegetation cover. Control bed shown above, trench bed below. Note that WFD data was not recorded for bed S2tb. The effect of daily soil temperature oscillations have not been removed from tension data.



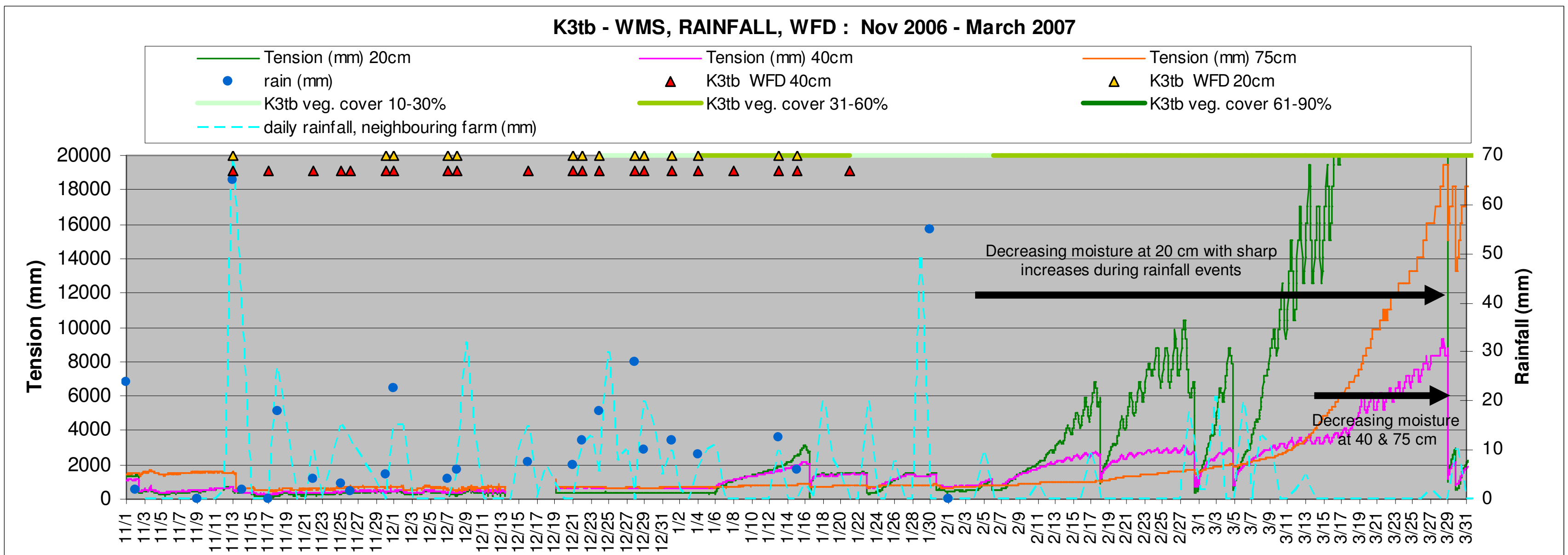


Figure 3.9: Farmer K's garden bed records: soil water tension, rainfall, irrigation, WFD and vegetation cover. Control bed shown above, trench bed below. Note that WFD records are not considered reliable and irrigation was not recorded. The effect of daily soil temperature oscillations have not been removed from tension data.

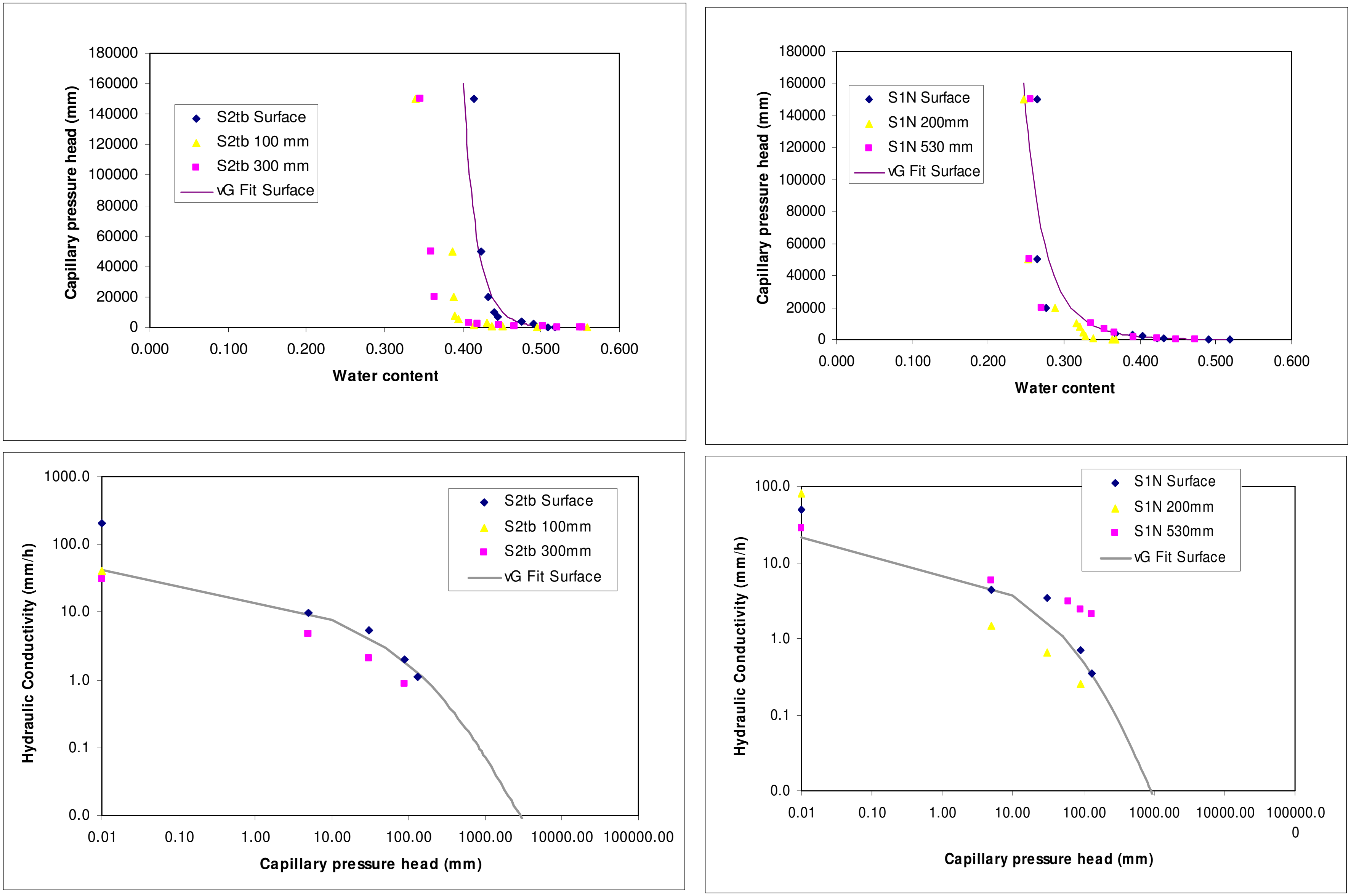


Figure 3.10: Water content and hydraulic conductivity curves for sites S2tb and S1n.

At Farmer K's site (Figure 3.9), soil water tensions at all depths in the control bed fluctuated more dramatically through most of the rainy season than they did within the trench bed, which maintained a consistently low tension (indicating relatively high moisture). This pattern continued until early February with the onset of the longer (10 to 16 day) dry spells. During this time tensions began increasing at all depths in the trench bed as the soil profile became drier, though tensions at 75 cm did not increase as dramatically as they did in shallower depths until early March. Tension in the shallower soils (20 and 40 cm) became more responsive to rainfall events, dropping significantly with specific events, and climbing again soon afterward. In the control bed tensions also rose dramatically at 20 cm in early February, however tensions increased more rapidly at this depth than in the trench and without the increased responsiveness to rainfall events recorded in the trench bed. Tensions increased somewhat at 40 and 75 cm in the control bed as well during this period, also without responsiveness to rainfall events. Soil moisture at 75 cm in the control bed diminished somewhat during prolonged dry spells in February and March, but it remained relatively stable compared to the same depth in the trench bed, where tensions began climbing significantly in early March. Similar to Farmer S's garden, the trench bed had some vegetation cover, while the control bed had no cover throughout the prolonged dry spells in February and March. Such differences in vegetation cover can partially explain tension records during this time because less moisture would have been lost by transpiration from deeper within the control bed profile, while significant moisture losses could have occurred near the surface due to the high soil water evaporation allowed by lack of cover.

It is possible that greater connectivity between pore spaces in the trench beds relative to control beds, combined with transpiration from vegetation cover, is responsible for the gradual but consistent increases in tension found in trench bed soils during prolonged dry spells. However, during the wetter months, including shorter dry spells spanning up to 6 days, the trench beds appear to retain more moisture throughout the soil profile than do the unmodified control beds. Trench beds were observed to have subsided considerably (up to approximately 20 cm) 18 months after they were constructed, which could result in less pore space connectivity and less resulting moisture loss in trench beds during dry spells after the first season of use.

3.2 Run-on ditches

Run-on ditches were constructed at Farmer D's garden with significant design work and labour provided by researchers. Later in the season, after observing increased water availability in the garden, Farmer D and his wife assisted other family members to construct ditches in their own gardens. Soil in Farmer D's garden control bed and run-on ditch bed was observed to consist of a red-brown *sandy silt with clay* from 0 to 70 cm in depth with manure dug into the top 10 cm (Figure 3.7). A very hard layer (possibly a plough-pan caused by multiple years of hoeing in the garden) was observed from 10 to 40 cm depth. The deep (40 cm) WFD was never activated in the control bed, while it was activated by rainfall twice (once during a 70 mm event) in the ditch bed. In both beds the 20 cm WFDs were activated only six times during the five-month data collection period due to rainfall, not irrigation, despite regular applications of 6 mm (Figure 3.11). Saturated hydraulic conductivity at this site (Figure 3.12) was fairly high (on the order of 300 mm/hour), while the unsaturated hydraulic conductivity was relatively low (between 0.1 and 7 mm/hour). This indicates a soil with a macro pore structure which allows rapid infiltration from a ponded water source, but very slow infiltration with tension applied water. This is particularly true for the surface layer and is reflected in the water retention characteristic, which has a high residual water content (0.318 at 150,000 mm). These values indicate a soil with a very tight surface layer, possibly even crusted, which permits rapid rain events (20 mm or more) to penetrate to the WFD depths through macro pores, but periodic applications of 6 mm of water are held up in the slow conducting and high retention matrix of the surface soils. Closer examination of the water retention characteristic reveals that the surface measurements at D1n indicate a high porosity (0.541 water content), which drains rapidly (without much increase in tension) to a value of 0.428, when significant tension is required to further drain water from the soil. In other words, the macro pores retain water between about 0.43 and 0.541, after which the water is held in a very tight matrix, where tensions of 20,000 mm are required to drain further significant amounts of pore water from the matrix. The "double curvature" nature of water retention at the surface of site D1n is indicative of a dual porosity medium. Deeper soils and those at the control bed for site S (approximately 1 km away) have a smoother transition between porosity and residual water content, suggesting a more uniform porosity.

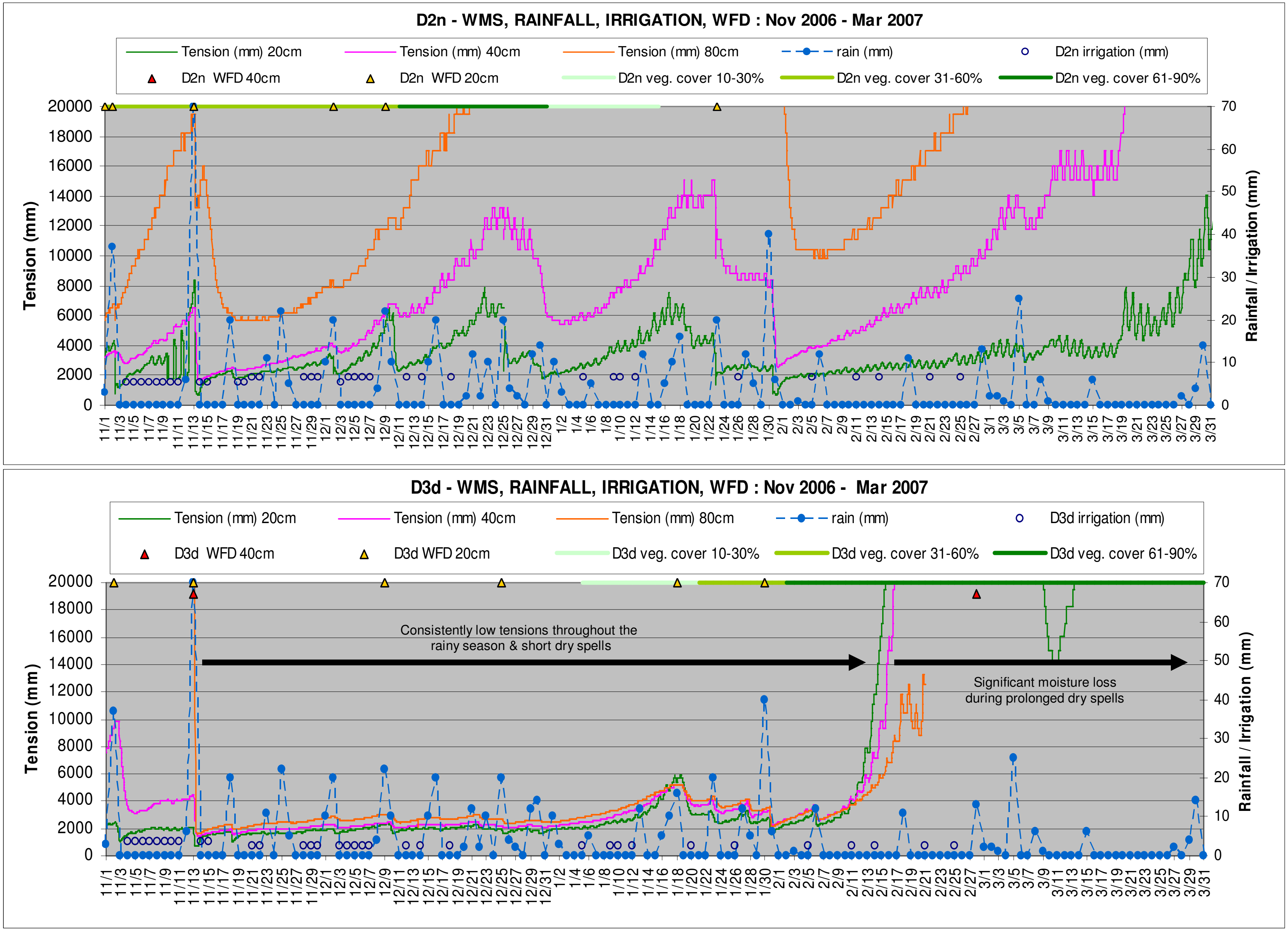


Figure 3.11: Farmer D's garden bed records: soil water tension, rainfall, irrigation, WFD and vegetation cover. Control bed shown above, run-on ditch bed below. Note that irrigation and WFD events were not recorded after March 4. The effect of daily soil temperature oscillations have not been removed from tension data.

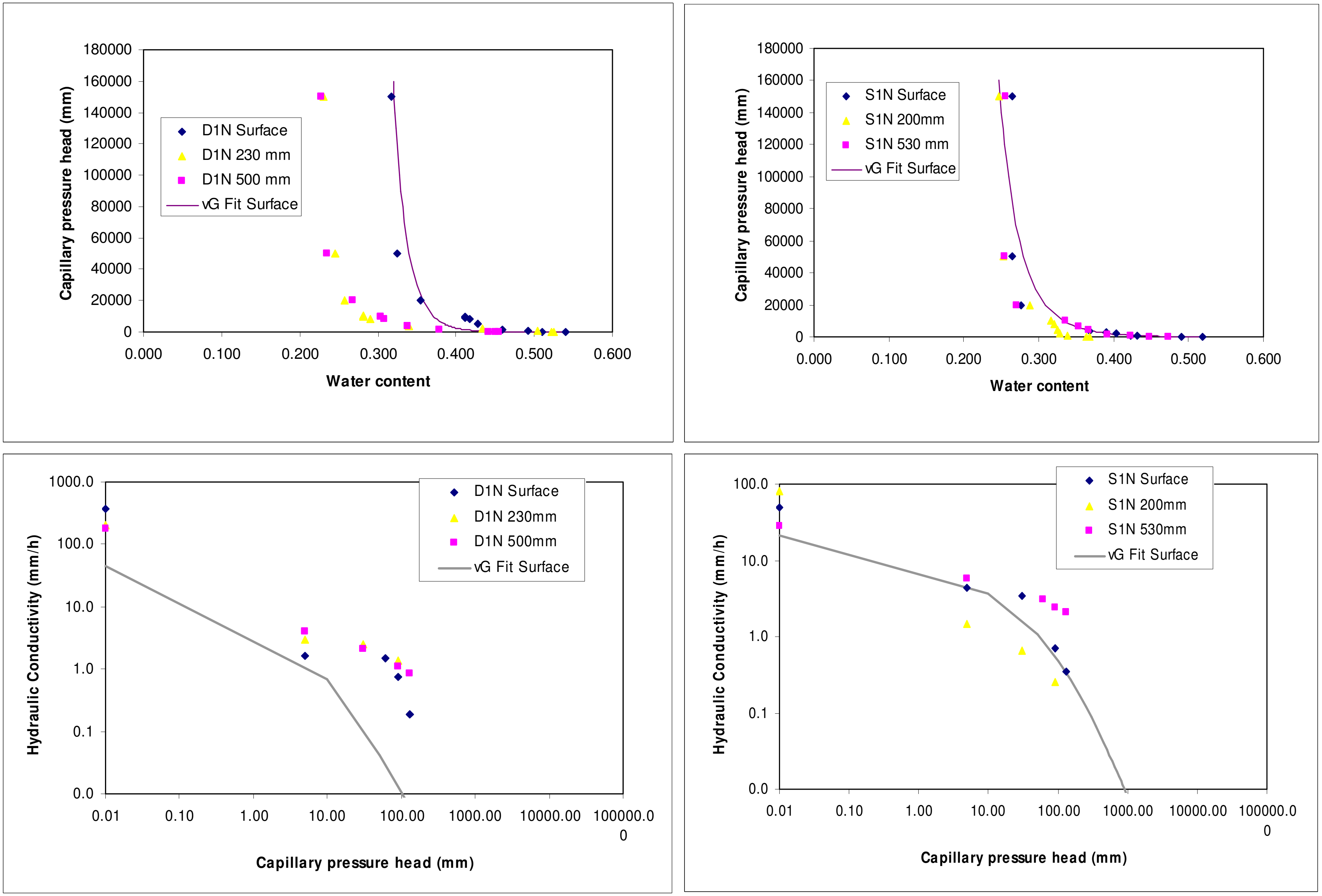


Figure 3.12: Water content and hydraulic conductivity curves for sites D1n and S1n.

After a 70 mm rainfall event on November 13th and during a consistently rainy period from then until early February, the run-on ditch bed (D3d) maintained a consistently low soil water tension (indicative of high moisture content) throughout the soil profile (Figure 3.11). Irrigation quantities applied to the run-on ditch bed were consistently less than that applied to the control bed (2.5 mm versus 6.5 mm), however, a large (though un-quantified) amount of water was added to the run-on ditch bed through the ditches themselves. The contribution of the ditches to irrigation was not quantified, as its source is rainfall falling within the garden getting trapped in the ditches until it infiltrated, as well as from runoff from the packed homestead area that was directed into the garden ditches via a connecting external ditch. Tension records from the control bed (D2n) showed that shallow (20 cm) soils stayed relatively moist during this period, but with a higher tension (greater moisture loss) between rainfall events than that recorded at any depth in the ditch bed. Less moisture was retained at 40 cm and considerably less at 80 cm in the control bed and only the rainfall events greater than 35 mm significantly increased soil moisture at both of these depths. With the onset of a series of prolonged (9 to 11 day) dry spells in February, soil in the run-on ditch bed began to lose moisture significantly at all depths, while soil in the control also lost moisture but at a more gradual rate. This may be partly due to transpiration associated with heavy (61-90%) vegetation cover in the ditch bed. The control bed had only very small, widely spaced seedlings planted in it during that time, which were irrigated often (although irrigation amounts were not recorded after March 4th), and may explain why the control bed maintained relatively high moisture at 20 cm depth until March 19th, well into the series of prolonged dry spells. It is also likely that additional evaporation occurred through the 20 cm deep sidewalls of the ditch bed that make up the run-on ditch walls. This additional avenue for evaporation created by the construction of ditches appears to actually reduce water availability in the run-on ditch beds during long dry spells, although it greatly increased the amount and stability of moisture available at all depths throughout rainy months and short, well spaced dry spells (up to 6 days). This suggests that run-on ditches may not be practical for use during prolonged dry spells and winter months when runoff is not available, while they may enhance water availability considerably during the rainy season. Additional monitoring of moisture content in run-on ditch beds and traditional beds with identical vegetation cover is needed to differentiate between the moisture loss due to plant transpiration and the added evaporation through the ditch sidewalls.

3.3 Drip irrigation

Drip irrigation was found to be impractical in Potshini, as the available drip kits were prone to malfunction or break and farmers believed that they did not provide enough water to the plants (compared to watering cans). Although it was suggested that farmers who had drip kits try re-filling the reservoir until they were satisfied that the plants received enough water, some farmers did not have the time to monitor the kits while they slowly drained. In a large garden or field a drip kit could potentially save time over hand watering, but in small, subsistence gardens, hand watering proved to be faster. In addition, drip kits and parts are not easily accessible in the Bergville district, which hinders innovation dissemination considerably. Leakage from the drip lines available for this research resulted in drip irrigation being used only minimally throughout the 9 month study, and insufficient information was acquired for determining its potential for enhancing availability of moisture and yield of the crop.

3.4 Wetting Front Detectors and the learning process

The significance of soil water holding capacity and wetting fronts can be difficult to grasp, especially when farmers have limited educational backgrounds or opportunities, as is the case in many rural South African communities. This is not surprising when the majority of commercial irrigators in South Africa, who are often well educated, do not monitor soil water status (Stevens *et al.,* 2005). After six months of facilitated experiments with WFDs, farmers in Potshini did understand that the WFDs could affectively tell them when the water had reached a certain depth. However, they had only used this information to change their irrigating practices in minor ways. Generally, the farmers said that they knew they could stop irrigating once the WFDs had been activated and did not irrigate again until the WFD indicators could be pushed down. This would not have resulted in a significant alteration of irrigation practices for most farmers however, because WFDs were primarily activated during rainfall events (not by irrigation), although there did appear to be a few instances of WFD activations in response to irrigation at Farmer S's site. Farmer N said she had changed from irrigating with 10 litres per day to using 20 litres every second day in order to activate the WFDs during irrigation events. Farmer D noted that the WFDs in his garden were only activated after heavy rain (greater than 20 mm in the control and 10 mm in the run-on ditch bed) and he did not wish to apply enough irrigation to activate them. This was confirmed by his field records, which showed that WFDs were never activated by irrigation, despite a regular application of 6 mm (Figure 3.11). WFDs in Farmer S's control bed were primarily activated by rain events as well, however, during a 6 day dry spell in January, both 20 cm and 40 cm WFDs did respond to irrigation on a nearly daily basis. During this period, irrigation was increased from the previous 1.5 mm to 3, 4 and finally 6 mm per day. WMS data from 20 and 40 cm depths in the same bed corresponded well with the WFD activations, showing sharp increases in moisture in response to irrigation, while the 80 cm WMS indicated very dry conditions deeper within the profile (Figure 3.8).

When questioned at the end of the field study, and again one year after research and facilitation had ceased, all farmers who had WFDs in their gardens said that they were useful because they "show if there is enough water in the garden". Farmer D added that the instruments tell him "how much water is needed" (although he never did irrigate with enough water to activate the WFDs) and they give him a "picture of what is happening underground". One of the three farmers participating in technical experiments, Farmer K, recorded activation events inconsistently, rarely re-set the WFDs and did not record irrigation. The manually recorded data set from her garden is therefore inconsistent, making it difficult to draw conclusions about the function and value of WFDs at this site. This same farmer reported a negative aspect of the WFDs, stating that she was unsure about where to dig around the instruments when planting or weeding.

One year after regular facilitation from researchers ceased, all four farmers using WFDs had moved and expanded their garden locations (partly due to a local municipality authority grant providing 10 m by 20 m of fencing to 20 Potshini homesteads) but had not relocated the WFDs into the new gardens. When questioned individually, each farmer said they believed the WFDs were useful tools and that they would have moved them if they had help from someone who understood how to install them properly. Although farmers had observed or assisted with the initial installation nearly two years prior they all lacked the confidence needed to repeat the installation on their own. Continuous use of WFDs, as well as potential instrument sharing from farmer to farmer in the future will require farmers to install the instruments themselves with limited assistance from researchers. After explaining the installation procedure to farmers during follow-up site visits, Farmer D said he would move one WFD to his new garden and leave the other two in the old garden for his sister-in-law to experiment with (the fourth had since broken at the stem, possibly from brittleness due to sun exposure). Farmer S said she would relocate her one functioning WFD to the new garden (the other three were missing pop-up indicators which appeared to have broken off as a result of sun exposure). Farmer K's and Farmer N's WFDs had all been broken prior to the follow-up visit when cows trampled the abandoned gardens. Results from a WRC project focused on WFD introduction suggest that extending the period of researcher facilitation with WFDs to two or three years could significantly improve farmers' understanding of their value as an irrigation management tool and increase the tendency to alter practices (Stirzaker *et al.*, 2004).

Another limitation on the continued use and dissemination of WFD technology is the somewhat fragile nature of the instruments, especially after prolonged sun exposure. Two of the four instruments that broke as a result of sun exposure had cracked only six months after the initial installation when the top of the stem was removed for inspection. This poses a significant obstacle to the successful adoption and dissemination of WFD technology because farmers in rural areas typically have no way of procuring WFDs or parts.

4. CONCLUSIONS AND RECOMMENDATIONS

Wetting Front Detectors appear to have good potential in the arena of Participatory Learning and Action in South Africa. However, to fully realize the potential of WFDs in subsistence gardening and farming, farmers and researchers need to engage in discussions and demonstrations or experiments related to the movement of water within the soil profile, such as rooting depth and its relation to wetting fronts as well as its significance in terms of plant production. Such discussions, demonstrations and experiments should be tied to a reflection process, wherein farmers and researchers use prior observations to continuously modify or adapt irrigation practices until farmers and researchers are satisfied with observed outcomes. During this nine month field study, farmers had not fully realized the potential for improving irrigation practices through WFD observations, and could not therefore disseminate an understanding of the true value of WFDs to other farmers in the community. This study was limited to a single growing season due to financial and other constraints, however, continuing the facilitated learning process over at least two growing seasons could significantly increase farmers' understanding and use of WFD technology to improve their irrigation schedules as recommended by Stirzaker et al. (2004). Trials recommended for further participatory learning include comparing irrigating often with shallow infiltration to irrigating less often with deeper infiltration; comparisons of drip, flood and bucket irrigation; and monitoring rooting depths with different irrigation schedules.

One of the constraints on experimenting and modification of irrigation practices currently is that most farmers in Potshini use community hand pumps to collect water from boreholes that are located some distance from their homesteads. The water is then carried by hand to the homestead in 20 litre containers. During the course of this study, farmers rarely applied enough irrigation to activate either the 40 cm or the 20 cm WFDs. Until water is more easily accessible (through on-site rainwater harvesting tanks for example), farmers will only be able to experiment with irrigation timing, as the total quantity available for irrigation is relatively small and fixed. Once farmers are comfortable with the concept of wetting fronts and their relation to rooting depth, crop yield and irrigation, incorporation of nitrate and solute analyses from irrigation water samples could also prove valuable in terms of adjusting irrigation practices to maximize water availability to the plant.

Two of the eight WFDs that were installed for this project broke after six months when the top piece was removed, as the plastic had become brittle from sun exposure. It is strongly recommended that UV resistant plastics are used in the further production of WFDs. Farmers in the Bergville area have no way of procuring WFDs or parts and their use cannot be sustainabley spread until they become more readily available. Even after overcoming these obstacles, the WFDs will still only be useful to a certain percentage of farmers because the farmers who are not interested in keeping records or in refining their practices, often due to the existence of more pressing livelihood activities or interests, will not take the time to evaluate WFD generated information, nor risk modification of their own practices. Not surprisingly, WFDs will be most valuable to people to who are seriously interested in learning about the dynamics of soil-water interactions in their fields or gardens for the purpose of improving their farming or gardening system.

Trench beds appear to consistently retain greater moisture throughout the profile than traditional beds in Potshini during regular rainfall events and short (less than 7 day), well spaced dry spells. However, greater connectivity between pore spaces in the trench beds relative to control beds may result in gradual but consistent moisture losses during prolonged dry spells. This suggests that while trench beds provide for better water availability to plant roots than traditional garden beds during consistent rains, they may be less advantageous during prolonged dry spells and dry winter months. Additional research spanning multiple seasons is needed to confirm these results however, because pore space connectivity may have less effect on moisture loss after the first or second season of trench bed use, as subsiding beds with time will have less pore space connectivity. Monitoring control and trench beds with minimal variation in vegetative cover would also strengthen the understanding of potential water availability associated with trench beds.

Run-on ditches in Potshini appear to maintain a relatively high, stable moisture content throughout the garden bed profile, compared to the control bed, during consistent rains and well spaced, short (less than 7 day) dry spells. However, they may not be practical for use during prolonged dry spells and winter months when runoff is not available, as significant moisture loss was observed throughout the run-on ditch bed profile with the onset of multiple prolonged dry spells. The cause of recorded moisture loss is likely to be a combination of increased evaporation through ditch sidewalls and increased plant transpiration due to dense vegetation cover (as compared to the control bed). Additional moisture content monitoring in run-on ditch beds and control beds through multiple seasons and with identical vegetation cover is needed to differentiate between the moisture loss due to plant transpiration and the added evaporation through the ditch sidewalls. Quantifying other water balance parameters, such as bed runoff and the amount of water entering the bed through run-on ditches would also help clarify the potential Water Use Efficiency associated with run-on ditches. Statistical analyses of crop yield data spanning multiple seasons could also provide insight into the value of run-on ditches.

Drip irrigation data was inconclusive because the available drip kit joints leaked throughout the field study and the participating farmer preferred to hand water rather than lose water through the line connections. In addition, drip kits and parts proved difficult to obtain, as they are not available for purchase in the Bergville district. Other farmers supplied with drip kits in Potshini also preferred not to use them as they did not feel that their vegetables received enough water (due to observations of small, wilting spinach and other plants), and because the kits tended to get clogged or break soon after they were set up. Drip irrigation may have potential to improve Water Use Efficiency, but additional testing with more robust equipment and various application strategies and bed sizes is needed to determine the true value and adoptability of drip irrigation in the Bergville district.

Manual data collection by farmers can be of significant value in building an understanding of an innovation's effect on soil water movement and other biophysical conditions. While farmer-driven experimentation does limit the control a researcher may have over the experiment, this is outweighed by the immediate benefit of aligning innovation development with the socio-economic as well as biophysical conditions present within the community targeted for innovation adoption. While it requires more time than traditional research, this form of PLA research empowers the farmers whose livelihood improvement is often the goal of agricultural research. The result is an innovation farmers understand how to operate and explain to others and that is suitable to local conditions. In other words, an innovation that is more readily adopted, adapted and disseminated.

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REFERENCES

ENVIRONMENTAL AND DEVELOPMENT AGENCY TRUST (1995) The People's Farming Workbook. David Philip Publications, Cape Town, RSA.

HERR K AND ANDERSON GL (2005) *The Action Research Dissertation: A Guide for Students and Faculty.* Sage Publications, London, UK.

IRROMETER CO. (2006) Moisture Sensor Agricultural Irrigation Design Manual. [Internet]. Irrometer Co., Irrigation Association, Riverside, CA, USA. Available from: http://www.irrometer.com/pdf/ADG.PDF. [Accessed: 22 October 2006].

KONGO VM and Jewitt GPW (2006) Preliminary investigation of catchment hydrology in response to agricultural water use innovations: A case study of the Potshini catchment – South Africa. *Physics and Chemistry of the Earth 31:976-987.*

KOSGEI JR and JEWITT G (2006) Realizing Food Security in Semi-Arid Agro-ecosystems of Southern Africa: Does the Potential Lie in Upgrading Rainfed Agriculture? Proceedings of the 10th Annual Searnet conference, 4th-6th December 2006; Mombasa, Kenya.

LORENTZ S, GOBA P and PRETORIUS J (2001) Experiments and Measurements of Soil Hydraulic Characteristics. Water Research Commission Report No.: K5/744 - Experimentation and Laboratory Measurement for Hydrological Process Research Project. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, RSA.

NGIGI SN, SAVENIJE HHG, ROCKSTRÖM J and GACHENE CK (2005) Hydro-economic evaluation of rainwater harvesting and management technologies: Farmers' investment options and risks in semi-arid Laikipia district of Kenya. *Physics and Chemistry of the Earth* **30** 772-782.

ROCKSTRÖM J (2000) Water resources management in smallholder farms in eastern and southern Africa: an overview. *Physics and Chemistry of the Earth* (B) **25** (3) 275–283.

ROCKSTRÖM J (2003) Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth* **28** (20-27):869-877.

RURAL INTEGRATED ENGINEERING (PTY) LTD. (2008) Concept Note for intensive food production at homestead level. Refinement Report 2007/2008 for Water Research Commission Project: K5/1575/4 - Participatory Development of Training Material for Agricultural Water Use in Homestead Farming Systems for Improved Livelihoods. Pretoria, RSA.

STEVENS JB, DUVEL GH, STEYN GJ and MAROBANE W (2005) The range, distribution and implementation of irrigation scheduling models and methods in SA. Water Research Commission Report No. 1137/1/05, Pretoria, RSA.

STIRZAKER R, STEVENS J, ANNANDALE J, MAEKO T, STEYN M, MPANDELI S, MAUROBANE W, NKGAPELE J and JOVANOVIC N (2004) Building Capacity in Irrigation Management with Wetting Front Detectors. Water Research Commission. WRC Report No. TT 230/04. Gezina, RSA.

STIRZAKER RJ, STEVENS JB, ANNANDALE JM and STEYN JM (2007) The Wetting Front Detector: a tool to help irrigators learn. Available from www.fullstop.com.au. [Accessed 17 March 2008].

STURDY JD, JEWITT GPW and LORENTZ SA (2008) Building an understanding of water use innovation adoption processes through farmer-driven experimentation. *Physics and Chemistry of the Earth.*

CHAPTER FOUR

Conclusions and Recommendations

1. CONCLUSIONS AND RECOMMENDATIONS

It is not adequate to promote innovations that scientific research has shown can improve crop yields or water conservation under given biophysical conditions without considering the socio-economic aspects of farmers' decision making. Innovation promotion should involve farmers' opinions and perceptions at the onset of the project, as should the process of choosing pathways for facilitating adoption and dissemination. Successful facilitation pathways often employ Participatory Learning and Action techniques that can be used with small groups of farmers to involve them in the process of choosing innovations to introduce to a community. Farmers may not be aware of nor understand the function of differing innovations, but they do know their own livelihood priorities and can help researchers identify the conditions that must be met for an innovation to be successfully adopted and disseminated.

In Potshini, and in other subsistence farming communities in Southern Africa, hands-on, monthly workshops that focus on problems identified by the farmers themselves can be a successful pathway for facilitating adoption. Group workshops provide a venue for farmers to share concerns and knowledge, which is an important avenue for innovation dissemination because farmers tend to adopt innovations that have been tried and introduced to them by other farmers. Through such workshops, farmer leaders can be identified and motivated farmers can be chosen for individualized training or farmer experimentation, which have been successful pathways for fostering thorough understanding of innovations. Experimentation allows farmers to assess the value of innovations they choose to study while improving their ability to make informed decisions through critical thinking and analysis, particularly when the farmers' own innovative abilities are respected and encouraged. It also develops their confidence in explaining the function of innovations to others. An additional benefit of workshops is that they provide a venue for group feedback on the reflection and planning phases of the action research cycle (Act-Observe-Reflect-Plan/Modify).

Gardens provide a small-scale, low-risk learning environment for experimentation through trial comparisons. Problem solving skills developed during garden trials can be extended to other aspects of rural life and agriculture. Additionally, gardens in Potshini had an obvious positive effect on the livelihoods of at least half of the farmers participating directly in this study by providing a continuous supply of diversified vegetable nutrients to the diet, saving money otherwise spent on vegetables or by providing income though selling produce to neighbours.

Wetting Front Detectors appear to have good potential in the arena of Participatory Learning and Action in South Africa. However, to fully realize the potential of WFDs in subsistence gardening and farming, farmers and researchers need to engage in discussions and demonstrations or experiments related to the movement of water within the soil profile, such as rooting depth and its relation to wetting fronts as well as its significance in terms of plant production. Such discussions, demonstrations and experiments should be tied to a reflection process, wherein farmers and researchers use prior observations to continuously modify or adapt irrigation practices until farmers and researchers are satisfied with observed outcomes. During this nine month field study, farmers had not fully realized the potential for improving irrigation practices through WFD observations, and could not therefore disseminate an understanding of the true value of WFDs to other farmers in the community. This study was limited to a single growing season due to financial and other constraints, however, continuing the facilitated learning process over at least two growing seasons could significantly increase farmers' understanding and use of WFD technology to improve their irrigation schedules. Trials recommended for further participatory learning include comparing irrigating often with shallow infiltration to irrigating less often with deeper infiltration; as well as comparisons of drip, flood and bucket irrigation. In addition, monitoring rooting depths for the different irrigation schedules could be a practical, farmer-determined indicator for WP as it relates to plant health.

One of the constraints on experimenting and modification of irrigation practices currently is that most farmers in Potshini use community hand pumps to collect water from boreholes that are located some distance from their homesteads. The water is then carried by hand to the homestead in 20 litre containers. During the course of this study, farmers rarely applied enough irrigation to activate either the 40 cm or the 20 cm WFDs. Until water is more easily accessible (through on-site rainwater harvesting tanks for example), farmers will only be able to experiment with irrigation timing, as the total quantity available for irrigation is relatively small and fixed. Once farmers are comfortable with the concept of wetting fronts and their relation to rooting depth, crop yield and irrigation, incorporation of nitrate and solute analyses from irrigation water samples could also prove valuable in terms of adjusting irrigation practices to maximize water availability to the plant.

Two of the eight WFDs that were installed for this project broke after six months when the top piece was removed, as the plastic had become brittle from sun exposure. It is strongly recommended that UV resistant plastics are used in the further production of WFDs. Farmers in the Bergville area have no way of procuring WFDs or parts and their use cannot be sustainably spread until they become more readily available. Even after overcoming these obstacles, the WFDs will still only be useful to a certain percentage of farmers because the farmers who are not interested in keeping records or in refining their practices, often due to the existence of more pressing livelihood activities or interests, will not take the time to evaluate WFD generated information, nor risk modification of their own practices. Not surprisingly, WFDs will be most valuable to people to who are seriously interested in learning about the dynamics of soil-water interactions in their fields or gardens for the purpose of improving their farming or gardening system. Such people are likely to be farmers who have already recognized a strong connection between food security or financial gain and improved homestead farming or gardening systems.

Drip irrigation data was inconclusive because the available drip kit joints leaked throughout the field study and the participating farmer preferred to hand water rather than lose water through the line connections. Like the WFDs, drip kits and parts proved difficult to obtain, as they are not available for purchase in the Bergville district. Other farmers supplied with drip kits in Potshini also preferred not to use them as they did not feel that their vegetables received enough water (due to observations of small, wilting spinach and other plants), and because the kits tended to get clogged or break soon after they were set up. Drip irrigation may have potential to improve WP, but additional testing with more robust equipment and various application strategies and bed sizes is needed to determine the true value and adoptability of drip irrigation in the Bergville district.

Trench beds appear to consistently retain greater moisture throughout the profile than traditional beds in Potshini during regular rainfall events and short (less than 7 day), well spaced dry spells. However, greater connectivity between pore spaces in the trench beds relative to control beds may result in gradual but consistent moisture losses during prolonged dry spells. This suggests that while trench beds provide better water availability to plant roots than traditional garden beds during consistent rains, they may be less advantageous during prolonged dry spells and dry winter months. Additional research spanning multiple seasons is needed to confirm these results however, because pore space connectivity may have less effect on moisture loss after the first or second season of trench bed use, as subsiding beds with time will have less pore space connectivity. Monitoring control and trench beds with minimal variation in vegetative cover would also strengthen the understanding of potential water availability associated with trench beds.

Run-on ditches in Potshini appear to maintain a relatively high, stable moisture content throughout the garden bed profile, compared to the control bed, during consistent rains and well spaced, short (less than 7 day) dry spells. However, they may not be practical for use during prolonged dry spells and winter months when runoff is not available, as significant moisture loss was observed throughout the run-on ditch bed profile with the onset of multiple prolonged dry spells. The cause of recorded moisture loss is likely to be a combination of increased evaporation through ditch sidewalls and increased plant transpiration due to dense vegetation cover (as compared to the control bed). Additional moisture content monitoring in run-on ditch beds and control beds through multiple seasons and with identical vegetation cover is needed differentiate between the moisture loss due to plant transpiration and the added evaporation through the ditch sidewalls. Quantifying other water balance parameters, such as bed runoff and the amount of water entering the bed through run-on ditches would also help clarify the potential Water Productivity associated with run-on ditches.

Manual data collection by farmers can be of significant value in building an understanding of an innovation's effect on soil water movement and other biophysical conditions. While farmer-driven experimentation does limit the control a researcher may have over the experiment, this is outweighed by the immediate benefit of aligning innovation development with the socio-economic as well as biophysical conditions present within the community targeted for innovation adoption. While it requires more time than traditional research, this

form of PLA research empowers the farmers whose livelihood improvement is often the goal of agricultural research. The result is an innovation farmers understand how to operate and explain to others and that is suitable to local conditions. In other words, an innovation that is more readily adopted, adapted and disseminated.

APPENDIX A

Capacitance Probe Data

site ID	date	value1 (% moisture)	value2 (% moisture)	Ave. value (%)	Depth (cm)	quality code
S1n	21-Jan-07	16	15.8	15.9	15	
S1n	9-Feb-07	18.6	18.7	18.65	15	
S1n	14-Feb-07	18.7	19	18.85	15	questionable
S1n	20-Feb-07	16.9	16.9	16.9	15	questionable
S1n	21-Jan-07	18.5	18.3	18.4	30	
S1n	9-Feb-07	18.5	18	18.25	30	
S1n	14-Feb-07	19.5	19.6	19.55	30	questionable
S1n	20-Feb-07	18.5	18.7	18.6	30	questionable
S1n	21-Jan-07	18.5	16.3	17.4	45	
S1n	9-Feb-07	17.9	17.7	17.8	45	
S1n	14-Feb-07	18.6	19.1	18.85	45	questionable
S1n	20-Feb-07	18.2	17.8	18	45	questionable
S1n	21-Jan-07	16.4	17.1	16.75	60	
S1n	9-Feb-07	17.9	17.7	17.8	60	
S1n	14-Feb-07	18.1	18.4	18.25	60	questionable
S1n	20-Feb-07	17.4	18.1	17.75	60	questionable
S1n	21-Jan-07	14.9	14.5	14.7	75	
S1n	9-Feb-07	15.4	15.2	15.3	75	
S1n	14-Feb-07	15.9	16.2	16.05	75	questionable
S1n	20-Feb-07	15.2	16.6	15.9	75	questionable
S2tb	8-Jan-07	17	17.8	17.4	15	
S2tb	21-Jan-07	14.9	14.2	14.55	15	
S2tb	9-Feb-07	10.4	10.7	10.55	15	
S2tb	14-Feb-07	12	11.7	11.85	15	questionable
S2tb	20-Feb-07	9.9	9.8	9.85	15	questionable
S2tb	8-Jan-07	18.1	17.3	17.7	30	
S2tb	21-Jan-07	12.7	12.2	12.45	30	
S2tb	9-Feb-07	11.9	10.8	11.35	30	
S2tb	14-Feb-07	13.1	12.5	12.8	30	questionable
S2tb	20-Feb-07	10.9	10.8	10.85	30	questionable
S2tb	8-Jan-07	15.5	15.1	15.3	45	
S2tb	21-Jan-07	11.8	9.4	10.6	45	
S2tb	9-Feb-07	8.8	6	7.4	45	
S2tb	14-Feb-07	11.8	11.6	11.7	45	questionable
S2tb	20-Feb-07	10.4	9.8	10.1	45	questionable
S2tb	8-Jan-07	22.4	21.8	22.1	60	
S2tb	21-Jan-07	16.7	16.8	16.75	60	
S2tb	9-Feb-07	12.7	14.5	13.6	60	
S2tb	14-Feb-07	16.3	18.3	17.3	60	questionable
S2tb	20-Feb-07	16	12.4	14.2	60	questionable
S2tb	8-Jan-07	21.6	21.9	21.75	75	
S2tb	21-Jan-07	17.5	17.5	17.5	75	
S2tb	9-Feb-07	17.6	17.2	17.4	75	
S2tb	14-Feb-07	18.5	18.7	18.6	75	questionable
S2tb	20-Feb-07	16.5	17	16.75	75	questionable
D2n	8-Jan-07	19.6	18.1	18.85	15	
D2n	21-Jan-07	15.5	16.1	15.8	15	

D2n	9-Feb-07	17.7	18.1	17.9	15	
D2n	14-Feb-07	17.6	18.1	17.85	15	questionable
D2n	20-Feb-07	16.3	17.5	16.9	15	questionable
D2n	8-Jan-07	17.8	16.9	17.35	30	
D2n	21-Jan-07	15.7	14.6	15.15	30	
D2n	9-Feb-07	15.3	15.4	15.35	30	
D2n	14-Feb-07	15.9	16.2	16.05	30	questionable
D2n	20-Feb-07	14.6	15.1	14.85	30	questionable
D2n	8-Jan-07	21.6	22.4	22	45	
D2n	21-Jan-07	18	17	17.5	45	
D2n	9-Feb-07	18.6	19.2	18.9	45	
D2n	14-Feb-07	18.1	18.4	18.25	45	questionable
D2n	20-Feb-07	17.2	16.6	16.9	45	questionable
D2n	8-Jan-07	22	21.8	21.9	60	
D2n	21-Jan-07	18.4	18.7	18.55	60	
D2n	9-Feb-07	19.7	20	19.85	60	
D2n	14-Feb-07	21.2	20.7	20.95	60	questionable
D2n	20-Feb-07	19.8	20.2	20	60	questionable
D3d	29-Dec-06	24.9		24.9	15	
D3d	5-Jan-07	22.3	21	21.65	15	
D3d	8-Jan-07	20.4	20.1	20.25	15	
D3d	21-Jan-07	19.3	18.4	18.85	15	
D3d	9-Feb-07	17.5	18.3	17.9	15	
D3d	14-Feb-07	15.2	15.3	15.25	15	questionable
D3d	20-Feb-07	12.4	12.3	12.35	15	questionable
D3d	29-Dec-06	18.9		18.9	30	
D3d	5-Jan-07	19.1	14.6	16.85	30	
D3d	8-Jan-07	19.1	15.1	17.1	30	
D3d	21-Jan-07	16.2	16.1	16.15	30	
D3d	9-Feb-07	14.3	17.1	15.7	30	
D3d	14-Feb-07	16.3	13	14.65	30	questionable
D3d	20-Feb-07	7.9	10.1	9	30	questionable
D3d	29-Dec-06	22.7		22.7	45	
D3d	5-Jan-07	22.9	18.7	20.8	45	
D3d	8-Jan-07	22	21.9	21.95	45	
D3d	21-Jan-07	20	17.1	18.55	45	
D3d	9-Feb-07	19.2	17.6	18.4	45	
D3d	14-Feb-07	18.8	18.4	18.6	45	questionable
D3d	20-Feb-07	9.6	12.3	10.95	45	questionable
D3d	29-Dec-06	19.1		19.1	60	
D3d	5-Jan-07	18.3	18.2	18.25	60	
D3d	8-Jan-07	18	19.8	18.9	60	
D3d	21-Jan-07	19.1	18.4	18.75	60	
D3d	9-Feb-07	17.5	16.9	17.2	60	
D3d	14-Feb-07	16.6	17.2	16.9	60	questionable
D3d	20-Feb-07	11.8	11.6	11.7	60	questionable
D3d	29-Dec-06	22		22	75	
D3d	5-Jan-07	19.8	20.8	20.3	75	
D3d	8-Jan-07	20.4	20.5	20.45	75	
D3d	21-Jan-07	16.5	17.4	16.95	75	
D3d	9-Feb-07	16.3	18.4	17.35	75	
D3d	14-Feb-07	17.9	15	16.45	75	questionable
D3d	20-Feb-07	16.2	16.7	16.45	75	questionable

K4n	20-Dec-06	26.7		26.7	15	
K4n	29-Dec-06	27.6	27.4	27.5	15	
K4n	8-Jan-07	17.2	18.7	17.95	15	
K4n	21-Jan-07	12	11.9	11.95	15	
K4n	9-Feb-07	12.1	11.9	12	15	
K4n	14-Feb-07	11.7	12.1	11.9	15	questionable
K4n	20-Feb-07	10.7	10.8	10.75	15	questionable
K4n	20-Dec-06	14.4		14.4	30	
K4n	29-Dec-06	15	17.7	16.35	30	
K4n	8-Jan-07	13.6	13.7	13.65	30	
K4n	21-Jan-07	9.2	9.3	9.25	30	
K4n	9-Feb-07	8.2	7	7.6	30	
K4n	14-Feb-07	7.4	5.2	6.3	30	questionable
K4n	20-Feb-07	8.5	8.3	8.4	30	questionable
K4n	20-Dec-06	10.2		10.2	45	
K4n	29-Dec-06	12.1	10.1	11.1	45	
K4n	8-Jan-07	11.1	11.3	11.2	45	
K4n	21-Jan-07	6.6	5.9	6.25	45	
K4n	9-Feb-07	3.7	2.8	3.25	45	
K4n	14-Feb-07	0.9	4.1	2.5	45	questionable
K4n	20-Feb-07	4.5	4.5	4.5	45	questionable
K4n	20-Dec-06	20.1	14.8	17.45	60	
K4n	29-Dec-06	21.3	21.4	21.35	60	
K4n	8-Jan-07	21.2	20.9	21.05	60	
K4n	21-Jan-07	13.2	12.2	12.7	60	
K4n	9-Feb-07	9.9	10.1	10	60	
K4n	14-Feb-07	12	13.4	12.7	60	questionable
K4n	20-Feb-07	10.2	8.8	9.5	60	questionable
K3tb	29-Dec-06	32.4	30.3	31.35	15	
K3tb	8-Jan-07	31.7		31.7	15	
K3tb	21-Jan-07	20.6	19.3	19.95	15	
K3tb	9-Feb-07	19.7	20.8	20.25	15	
K3tb	14-Feb-07	19.9	19.4	19.65	15	questionable
K3tb	20-Feb-07	16.2	16.1	16.15	15	questionable
K3tb	29-Dec-06	21.2	19.3	20.25	30	
K3tb	8-Jan-07	20.1		20.1	30	
K3tb	21-Jan-07	14.7	16.4	15.55	30	
K3tb	9-Feb-07	15.8	17.6	16.7	30	
K3tb	14-Feb-07	16.2	15.4	15.8	30	questionable
K3tb	20-Feb-07	14.3	14	14.15	30	questionable
K3tb	29-Dec-06	13.4	15		45	poor
K3tb	8-Jan-07	13.7			45	poor
K3tb	21-Jan-07	17.4	17.5	17.45	45	
K3tb	9-Feb-07	17.1	17.3	17.2	45	
K3tb	14-Feb-07	16.1	18.2	17.15	45	questionable
K3tb	20-Feb-07	14.9	15.7	15.3	45	questionable
K3tb	29-Dec-06	6.7	12.8		60	poor
K3tb	8-Jan-07	0			60	poor
K3tb	21-Jan-07	20.1	18.9	19.5	60	
K3tb	9-Feb-07	18.7	19.1	18.9	60	
K3tb	14-Feb-07	19.7	19.2	19.45	60	questionable
K3tb	20-Feb-07	17.2	17.6	17.4	60	questionable

APPENDIX B

Interview Questionnaire Forms

Date:………… Time: ………….   Location:…..……………..S ……..……………E

Agricultural Innovation Adoption & Dissemination Interview: Conducted at 50 homesteads in Potshini

Name of Enumerator___________________________________
Household Name_____________________________________
Respondent Name____________________________________
Male____ Female____ Head of household: Yes No

1. How long has your family been in the area? _________
2. Where you farming before you came here? __________
3. Did family participate in Landcare Project? _______yes _______no

4. Income (place letter only next to those that provide some income for family):

SOURCE	M = most, S = some, L = little bit	**SOURCE**	M = most of family income comes from this source
Pension, grant, welfare		Livestock sales	
Crop sales		Beer Sales	
Fruit and vegetable sales		Religious/traditional practices	
Clubs/coops **specify**		Buying and selling goods	
Remittances (from relatives working outside Potshini)		Technical skills (sewing, baking, crafts, etc.)	
Construction		Other **specify**: (daga?)	
Other labour sales			
Hiring out equipment or cattle			

5. Throughout the year, how much of your family's food comes from:
(A = all, M = most, S = some, L = little bit)
Crops grown on your farm ______ Vegetables from your garden ______
Purchased food (mealies , etc.) ______ Family's livestock / eggs ______
Other (**specify**) ______ _________________________________
Does family get enough to eat each year? _____yes _____no

6. What does family eat for main meal? ____
What else is eaten each day? ______________________ Special occasions? ___________
What do small children (1 – 5 years old) eat? _______________________________________

7. Have you had your soil tested (to see what kind of fertilizer / lime may improve soil)? ____yes ____no

8. How much money was spent on seeds / seedlings in 2006? __________________________

9. What kind of training(s) would benefit you & your family?
[EXAMPLES: financial (bank accounts, getting loans, planning/running a business, etc.); Agricultural practices (no-till, soil nutrients, saving water, etc.); gardening practices (pests, mulch, harvesting, saving water, etc.); grazing practices / planning; marketing (finding buyers, advertising, making contracts, etc.].

10. What type of development program(s) could benefit you & your family? [EXAMPLES: Farmer forums, ARC trials, DoA projects / workshops, SSI trials, Farmer Learning Workshops]

			If no longer in use, do not continue with questions -----> use space to explain why no longer used						
INNOVATION **IN THE FIELD**	Tried but no longer in use **(why not?)**	What do you have to buy for this?	Currently in use **(# of yrs)**	Who introduced this to you? (FLW = Farmer Learning Workshop)	What are the benefits?	What are the negatives?	How many hrs extra labour is involved?	Who have you taught this to?	Will you teach anyone else? (if not, why?)
manure (mquba)									
Fertilizer (manyalo)									
minimum-till									
pesticide									
mulch / crop residue									
lime									
intercropping									
crop rotation									
herbicide									
other:									
IN THE GARDEN	When did you / your family start gardening? __________ How did you get the idea of starting a garden? ____________________________								
straw in krall manure									
liquid manure									
trench bed									
manure in top few cm									
mulch									
run-on ditches									
drip kit									
TP rolls (for cutworm)									
chilli-soap water									
ash									
fruit planted									
napier planted									
peanuts planted									
other:									

Agricultural Innovation Adoption & Dissemination: Potshini

Critical Thinking Development Interviews – conducted with the 6 participating farmers after first field season of facilitated, farmer-driven technical experimentation

1. What made you decide to expand your garden?

2. Why did you decide to try using a trench bed?

3. Would you make more trench beds? Why/why not? When would you make another?

4. Have you learned anything from the records you are keeping? Have you used them to make decisions to change anything you do in the garden?

5. When plants get big, do they require water less often in TB vs. normal bed?

6. Does it matter to you if you water every day or every 2^{nd} day (using same total amount of water)?

7. Do you kill all insects & frogs that go into the garden? Why/why not? If no did you used to / when did you stop?

8. What do you do in a day besides gardening?

9. Who decides to buy seed / seedlings for garden (must you ask permission)?

10. Has gardening changed anything about how people in the household interact?

APPENDIX C

Explanation of Matrix Scoring Methodology

Matrix Scoring Description:

Matrix scoring is a tool by which certain issues are ranked against a list of criteria agreed upon by consensus within a group.

Objectives:

- To rank and prioritise identified objects (e.g. maize varieties, different crops, etc.), problems (e.g. lack of water, bad road conditions, etc.), solutions (e.g., improving the availability of clean water, improving road conditions, etc.), project ideas (e.g. drilling a borehole, rehabilitating the road to the sub-district centre, etc.), or technical alternatives of a certain project.
- To make the reasons and the underlying criteria for this prioritisation or decision visible.

Key questions:

- Which problems or solutions or projects are prioritised by different groups in the village/ community?
- Which criteria are used by local people to determine their priorities?
- How do people rank these criteria?
- How different are the preferences and perceptions between different groups within the village/ community?

Activities:

1. Explain to the village sub-group that they should prioritise the already identified problems or solutions or project ideas in a transparent way, discussing openly the reasons why some problems, solutions or project ideas are perceived as being more important than others.
2. Ask them to draw up a matrix with the problems, solutions or project ideas across the top.
    - In case you facilitate a **matrix scoring on problems**, ask the village sub-group for each problem in turn. "Why is it important to tackle this problem?". They might come up with answers like "because it is urgent", "because it affects the majority of village people", "because it is easy to solve", "because it reduces our income", etc. Ask them to list all the answers/ criteria down the leftside of the matrix.
    - In case you facilitate a **matrix scoring on solutions** or project ideas, ask the village sub-group for each solution or project idea in turn: "What is good about this solution/ project idea?" , until there are no more replies. Then ask for each in turn: "What is bad about this solution/ project idea?"
3. Support them in turning all negative criteria mentioned {'expensive', 'difficult to put into place') into positive ones {'cheap', 'easy to put into place').
4. Ask them to reflect what would happen if they did not do this {the answer should be that the scoring would not be consistent. They would give a high score to a positive criterion in some cases and a high score to a negative criterion in others).

5. Ask them to list all the answers/ criteria down the left side of the matrix some of the criteria might overlap with others very much, therefore, support them in bringing such criteria together into one.
6. Now ask the sub-groups to decide how far each criterion is fulfilled by each problem, solution or project idea. Ask them to distribute a given number of counters {e.g. stones, seeds), maybe 25 {depending on the number of columns), within a row, filling each box with the number they think represents the degree to which the problem, solution or project idea fulfils the respective criterion of that row.
7. Ask them not to continue with the second row until everybody is content with the result of the scoring along the first row. Remind them to record the scorings directly onto the matrix.
8. After completion of the matrix, ask them to count the sums per each problem, solution or project idea {along the columns) and to record the overall ranking of the objects.
9. Ask them to prioritise one to three criteria they find most important and to check the results of the scoring, if they had decided only upon these criteria, against their first result, which considers each criterion as being of the same importance.

Time:

1 to 1.5 hours

Materials:

Poster size paper, a marker and any material (such as dry beans) that can serve as a symbol. Alternatively, sandy ground, a stick, and any material that can serve as symbol.

Hints:

- Matrix scoring is probably one of the most difficult tools, but perfect for producing reasons for a decision.
- Turning negative into positive criteria requires some 'brainwork'.
- It is very difficult to score problems, since you can hardly ask: "What is good/ bad about the problem?", but very useful for ranking solutions or project ideas.
- It is absolutely necessary to rank the criteria in order to cross-check the results, if only the most important criterion had been considered - most problematic in this tool is that criteria are given equal weight.
- An appropriate size of the matrix is: not more than 5-8 items and not more than 5-8 criteria.

NOTE: The above description was used to design the matrix scoring activity used during this research project and was taken directly from:

Berg, C; Beck, C; Beckmann, G; Chimbala, C; Erko, C; Fleig, A; Kuhlmann, M; and Pander, H. 1997. Introduction of a Participatory and Integrated Develpment Process (PIDEP) in Kalomo District, Zambia - Volume II - Manual for Trainers and Users of PIDEP. Centre for Advanced Training in Agricultural and Rural Development, Humboldt University, Berlin, Germany.