Quantifying the impact of in-field rainwater harvesting (*IRWH*) production techniques on household food security for communal farmers in Thaba Nchu, Free State Province

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Abstract

The paper investigates the impact of employing in-field rainwater harvesting (IRWH) production techniques on household food security for communal farmers in Thaba Nchu, by estimating the minimum area of land that a representative household needs to cultivate in order to meet its requirements. First, using a poverty datum line for South Africa, annual income required by an average household for food and other basic necessities (shelter and clothes) is calculated, given a specific level of non-farm income for a typical household in the study area. Second, the caloric requirement for an average household's is estimated by using the daily caloric requirement of each member of the household. The household uses its income from non-farm sources to purchase food and where necessary supplemented with income from the sale of non-food agricultural production. In both cases minimum farm size is influenced by output levels and by profitability of crop production under IRWH techniques.

1. Introduction

The South African agricultural sector has a dual nature (Vink and Kirsten, 2003; Ortmann and Machethe, 2003; National Department of Agriculture, 2001). The sector comprises of commercial farmers occupying (84%) of agricultural land and the remainder (16%) occupied by small-scale and subsistence farmers. Most of the small-scale and subsistence/communal farmers are found in the former homelands areas. These areas are in general marginal for crop production as they are mostly semi-arid to arid with only a small proportion of the land under some form of irrigation. Despite the aforementioned, the majority of South Africa's poor (72%) lives in these areas and relies mostly on rain fed agriculture (Ortmann and Machethe, 2003; National Department of Agriculture (NDA), 1998; 2001).

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In general, agricultural productivity and production in the subsistence/communal sub-sector is very low. Low levels of production coupled high inter-annual variability leave households living in poverty and vulnerable to food insecurity. In addition to rain fed crop production, most farm households raise livestock and also engage in commercial activities. Migration, particularly by men and young people to larger urban centres is also common.

Rain fed agriculture will, for the foreseeable future, continue to be an important source of food for an increasing population in developing regions of the world for many (FAO, 1990; Parr *et al*, 1990). If poverty reduction is to be achieved, there is a need for efficient use of water and land in both rain fed and irrigated agriculture to meet future food demand and growing competition for productive resources (Fox and Rockstrom, 2003). Sustained growth in agricultural productivity and production is seen as critical to improvements in food security for rural populations (Ortmann and Machethe, 2003; Weibe, 2001), as it can translate into increased food supplies and lower food prices for consumers. Secondly, growth in agricultural productivity could result in higher incomes, thus an improved ability to purchase food and other basic necessities, for many food-insecure households who earn their livelihoods through agricultural production.

As a potential solution to the problem of water shortage and to increase land utilization for agricultural production in semi-arid rural areas of South Africa, the Agricultural Research Council has developed new production techniques that incorporate water conservation (Botha *et al*, 2001) called in-field rainwater harvesting (*IRWH*) techniques. The techniques combine the advantages of water harvesting, no till, basin planting and mulching on high drought risk clay soils. The *IRWH* techniques reduce total runoff from the field to zero and evaporation from the surface considerably (Botha *et al*, 2001). In addition the techniques have also been shown to increase farmers' income and reduce production risk significantly (Kundhlande *et al*, 2004).

If new production technologies are to have maximum impact on poverty alleviation, they have to be applicable under conditions within which small scale resource poor farmers operate. It is also important that the techniques should be applicable to the resources at the farmers' disposal. In Thaba Nchu, the site of the case study presented in this paper, land is the most readily available productive agricultural resource; each household has a specific amount of land available for arable production. While the *IRWH* techniques examined are expected to be suitable for application in the study area, there is a need to determine the amount of land required by an average farm household to produce enough food for itself or to enable it to generate sufficient income. As land and water become increasingly scarce, agricultural growth that depends more and more on yield-increasing technological changes are preferred. Also of serious concern regarding the development of new technologies is how these technologies will affect the poor. If the poor are left behind and rural inequalities worsen, agricultural growth may fail to achieve its intended objectives. Thus the new technologies should be applicable for farmers with small farm sizes and without significant endowments of other factors of production.

The rest of the paper is structured as follows: the first section gives a brief description of the *IRWH* techniques, followed by a discussion of the data used and the study area. The analytical framework is presented in the third section after which the empirical results and discussion are presented. The paper ends with some conclusions and recommendations.

2. In-field rainwater harvesting (*IRWH*) techniques

The *IRWH* techniques investigated in the paper are based on water harvesting. *IRWH* can be looked at as a specific technique of water harvesting, but in this paper the different variants of *IRWH* will be looked at as different techniques. The basic structure of the *IRWH* system comprises a 2-metre runoff strip along the slope of the field (catchment area) and 1-metre basin (storage) area across the slope of field and at the end of the runoff strip. In this way, runoff is directed and stored into the basin area.

The basic structure of the *IRWH* system can be altered by the use of different mulches in the basin and runoff area to give six different *IRWH* technique variants. The mulch can be organic (crop residue or grass) or inorganic (stones) and is applied either in the basins or the runoff surface. In its simplest format, there is the *BbBr* technique where there is no use of organic or stone mulch in neither basins nor the runoff strip. An improvement to *BbBr* is achieved by applying organic mulch in the basins while the runoff strip is left bare, resulting in the *ObBr* technique. A further addition of organic mulch on both the runoff strip and the basin area results in the *ObOr* technique. From the use of organic mulch, the system can also be enhanced by the use of both the organic and stone mulches, resulting in another two *IRWH* techniques (*SbOr* and *ObSr*). In *ObSr*, the organic mulch is applied on the basins and the stone mulch on the runoff strip while *SbOr* uses the mulches in direct opposite to the former. The last *IRWH* technique relates to the sole use of the stone mulch on both the basins and runoff area and is called *SbSr*.

Mulches reduce evaporation, reduce soil movement and improve soil structure (in the case of organic mulch). As a result the productivity of the techniques will improve as the different mulches are used. The *IRWH* techniques are expected to be more productive than conventional techniques as they increase moisture available in the root zone for crop growth.

3. Data and study area

The data analysed in this paper were collected from on-station and on-farm trials in Glen and Thaba Nchu, respectively. On-station trials data was collected over three production seasons using the *IRWH* techniques while the on-farm trials were performed over the one production season (2001/2002).

Thaba Nchu is located 58 km east of Bloemfontein and was formerly part of the Bophuthatswana homeland. A large population lives in 42 villages around the town of Thaba Nchu. Low rainfall and high evaporation coupled with poor soils are the major constraints to agricultural production. According to Hensley *et al* (2000), the area is characterised as semi-arid and thus marginal for crop production.

Data on the household characteristics of rural Thaba Nchu was collected using a structured questionnaire. The information collected was used to determine the household composition, the sources of income and the types and quantities of food available for a household. A total of 124 household heads/representatives were interviewed from 4 villages (Paradys, Talla, Feloané and Yoxford). These villages were selected in order to capture the demographic and economic diversity of the study area.

The area has limited employment opportunities outside agriculture (Free State Province/World Bank, 1997). Like other rural areas in South Africa, poverty and food insecurity are the major problems facing households in the study area. Currently land is one of the readily available productive assets for the households in the study area. Each household has access to about 2 to 4 ha of arable land. In addition households have 0.2 ha residential land, a portion of which can be used as homestead garden on which a household can produce crops such as maize and vegetables. Since the withdrawal of government support to farming activities, most of the arable land is currently unused. This is in part due to lack of appropriate production technologies, low returns from production and other constraints (e.g., high input costs, low and erratic rainfall and poor market access.). Some of the arable land is seasonally used to graze livestock and the expansion of homesteads into these areas threatens the availability of this land for arable use. This implies, therefore, that the *IRWH* techniques will most likely be acceptable if they were to reduce the pressure on the land. In other words it means the techniques need to increase productivity such that it reduces the land needed for cultivation or at the least be able to produce more than conventional within the available land. In addition the technique should create incentives to engage in agricultural production that were eroded by the withdrawal of government support that was characterized by heavy subsidization of agricultural production. This means the techniques should be able to contribute towards the intensification of arable production in the study area. In order to contribute towards alleviation of the problems of food insecurity and unemployment, the available land needs to be put into efficient production so as to increase the food supply for the farm households and also generate additional income.

4. Analytical framework

A widely used definition of food security is access by all people at all times to enough food for an active and healthy life (Bickel *et al,* 2000). It includes at a minimum the ready availability of nutritionally adequate and safe foods and an assured ability to acquire foods in socially acceptable ways.

Hoddinott (1999) outlines four ways of measuring food security outcomes: individual intake, household caloric acquisition, dietary diversity, and indices of household coping strategies. Each method of measuring food security outcomes entails different methods of collecting and analyzing the data. For the purpose of this study the household caloric acquisition will be applied, as it is the method commonly used. While the method produces a crude estimate of the amount of calories available for consumption by the household, it is easy and quick to apply.

For this method, the data is acquired by asking the principal person responsible for preparing meals how much food he/she prepared over a period of time (about 7 or 14 days). The quantities are then used to determine the amount of calories available to the household, after accounting for processing losses. The conversion of the data on available quantities of food into calories is done in three steps: i) converting of all quantities into a common unit (e.g., kg), ii) converting the quantities into edible portions by correcting for processing losses, iii) converting the edible portion quantities into kilograms by the use of standard caloric conversions

Caloric requirements are dependent on individual characteristics like age, gender, weight, body composition, and health status as well as other factors like climate; but typically a reference person needs to be defined, as well as his or her caloric needs per day. This allows the use of household aggregating statistics like household equivalent to be used. There is no universal agreement on the caloric requirement figure per adult equivalent but the estimates range from 1,885 to 2,500 kilocalories (Smil, 1994; James and Schofield, 1990). These estimates thus provide a benchmark with which the food security status can be evaluated.

In the study, land is in most cases the only readily available productive asset, even though there is a perceived pressure on availability, which the households has access to. Therefore, if land is to be allocated, what would be a reasonable farm size to adequately cater for the household needs taking into recognition future pressure on land? This also becomes important if the structure of agricultural production has to change with the new technology. So land being the available production resource becomes an important variable in the production system, as output (household food/income availability) will be largely dependent on the land available for farming household to utilize.

Given this, the minimum area of land required can be determined by relating land to per hectare profitability (gross margin) and adult equivalent household income and/or caloric requirements. The average household income and caloric requirements were determined based on the adult equivalent. Average household adult equivalent (*ADEQ*) in the study was calculated based on household demographics following on Aliber (2003):

$$ADEQ = (A + 0.5C)^{0.9} \tag{1}$$

where *ADEQ* is adult equivalent, *A* is the number of adults in a household, *C* is the number of children in the family (household members below 15 years of age are classified a child).

After the determination of the size of household in terms of adult equivalent units, the household's income requirement for a year is calculated as follows:

$$HHIR_y = ADMIR*ADEQ*12 \tag{2}$$

where $HHIR_y$ is the household income requirement per year, *ADMIR* is the adult monthly income requirement estimate for rural South Africa[2] and *ADEQ* is the adult equivalent.

[2] *The study uses the poverty line (May, 1998) as the minimum monthly income required by an adult.*

The amount of annual income required to enable a household to meet its basic needs, $HHIR_y$ can be obtained from a number of sources - crop and livestock sales, wage income, remittances and social grants (old age pensions, disability and child support grants). The sum of the income from other sources and from crop production indicated the total income generated by the household.

The minimum area of land required was determined by dividing the difference between total household income requirement per year and total income from other sources by the average per hectare income from production by a typical crop mixture. This implies:

$$W_m = (HHIR_y - HI_{os})/FI_{cm} \quad (3)$$

where, W_m is the minimum area of land required, $HHIR_y$ is the household income requirement per year, HI_{os} is the household's income from other sources, FI_{cm} is the net farm income from a typical crop mix[3]. The net farm income is determined by the use of enterprise budgets that were developed for each crop and under each *IRWH* production technique.

The household caloric requirement was determined based on the reference person's daily caloric requirement, from which the household caloric requirement was estimated by using the commonly consumed meals and amounts consumed of each food type. Since the household meals are carbohydrate based, it is assumed the source of the carbohydrates (maize) is produced from the household's own farm production and the other food types are purchased. After the determination of the quantities required of each food type, their cost is also determined so as to estimate the required additional income to acquire purchased items.

The theoretical framework as explained in the foregoing analysis is used to build a user friendly computer simulation model quantify the impact on land requirements when using *IRWH* techniques. The simulation model integrates the enterprise budget analysis with the two food/income security approaches used in the study. The variables that need to be specified to run the model are household composition (adults and children), available farm size, preferred

[3] *The typical crop mix is assumed to include maize (40%), sunflower (30%) and dry beans (30%). This is intended to fully maximise the returns to production should a farmer adopt more productive IRWH techniques and increase his surplus income. The calculation of total farm income does not include the fixed costs since these are incurred at specified intervals and the costs are relatively small as they mostly account for only 10% or less of the total cost structure. In addition, the level at which the technique is applied is over small areas of land with little demand for mechanization.*

crop combination, and the variable input and output prices. For a specified level of variables, the model will compute the crop gross margin (profit), net farm income, crop enterprise budget and the minimum farm sizes (caloric and income) that will be displayed as the output.

5. Empirical results and discussion

First, this section presents a summary of the household socio-economic characteristics in Thaba Nchu. These are used as raw data for the calculation of the minimum household area required to ensure food/income security for an average household in the study area. The determination of minimum farm size uses two slightly different but complementary methods, the household income requirement method and the household caloric requirement method.

5.1 Household socio-economic characteristics

Table 1 presents the socio-economic characteristics of a typical household in the study area. The average household size in the study area in 2001 was 5 members. On average each household consisted of 2 adults and 3 children. The estimate of the adult equivalent for the study area is 3. The poverty line estimate for rural South Africa is R353 which is used as a proxy for the minimum income requirement for an adult household member per month (May, 1998). Substituting these values into equation 2, gives the household income requirement per year as R12,539 for an average household. The average income from non-farm sources (off-farm employment, social grants and remittances), accounts for R6,767 per year of the total household income per year.

Social grants and remittances make up a large proportion (53%) of the total household income; therefore the other 47 percent should come from the household farm enterprise(s). Another important observation from the table is that, for the survival of the families, at least one member receives a government social grant (old age pension, child support grant, and/or disability grant). This further necessitates the need for intervention to enable households to generate income or produce their own food if they are to have sustainable household livelihoods. Since arable farming should provide the shortfall in income requirement, there is a need to determine the minimum area that will be required to produce enough food/income to offset, at the least, the household food/income deficit. It follows therefore that if the *IRWH* techniques are to prove worthwhile, they are more likely to be favoured by the farmers, as they will provide an alternative to total dependence on external income sources.

Table 1: Socio economic characteristics of an average household in the study area, 2001

Household Characteristics	Average
Household size	5
Adults	2
Children	3
Adult equivalent	3
Adult income requirement (per month)[4]	R353
Household income requirement (per year)	R12,539
Social grants (per month)	R328
Remittances (per month)	R236
Total off farm income (per year)	R6,767

As shown by the high dependence on non-farm income, it is important that those members who are in off-farm employment stay in their jobs in order to supplement the household income. Nonetheless, the land available for arable production should be enough in order to cater for job losses. The majority of off-farm employment is in the unskilled and semi-skilled job market. In this market there is a lot of job insecurity due to the high competition, therefore the household needs a buffer in the farm size to cater for mishaps in the job market. Therefore, the farm size will be a strategy to deal with these shocks as it is more rigid than the availability of jobs.

5.2 Minimum farm area based on income requirement

In the calculation of minimum area based on average household income requirement, the income deficit was divided by the per hectare production (total gross margin) of a combination of the crops used in the study for a given proportion of each. Gross margin is used as opposed to net margin since the fixed costs are relatively small. In addition, the greatest investment is in labour in the establishment of the system. This cost is incurred periodically (intervals of 3 to 10 years, depending on the specific *IRWH* technique used). Thereafter, the farmer only needs to repair/rehabilitate some parts of the system.

Given the importance of maize in the study area (as a staple food), the farmers are most likely to grow more maize than either sunflower or beans. To provide for this, it was assumed that the maize crop will at least take up 40 percent of the cropland and the other 60 percent were shared equally between sunflower

[4] *The adult income requirement is based on the poverty line by May (1998). This is assuming that the households are able to meet all their household needs.*

and dry beans. Minimum farm sizes were calculated for the different production techniques and the results are presented in Table 3 together with those from the caloric requirement approach.

5.3 Minimum farm area based on household caloric requirement

The determination of minimum farm area is based on the household caloric demand of an average household. The reference person is an adult person aged 30-60 years weighing 60 kg and involved in moderate activity thus requiring on average 2500 kilocalories per day (Hoddinott, 1999). According to the literature, 60 percent of the energy required is obtained from the edible portions of carbohydrates, 15 percent from proteins and the remaining 25 percent from fats and oils. The question then is to determine how much of each food type will be required to be able to meet the caloric needs of an average person

For this technique, a typical meal for a household comprises maize porridge, milk, meat some vegetables and oils or fats. The quantities of each required per day for an average adult were calculated with reference to a food pyramid[5]. Table 2 shows the quantities required, for an adult person, of each food type in a typical meal for the study area and the way they are sourced. The sources of food are either own production or purchased.

Table 2: Household food requirements to meet daily energy and nutrient requirement per adult equivalent in the study area, 2001

Item	Quantity	Source
Maize meal	400g	Own production
Milk	500ml	Purchased
Meat	60g	Purchased
Vegetables/fruits	215g	Purchased
Fats and oils	69ml	Purchased

Of the food items that a typical household would require, maize meal is from own production (Table 2), all the other food items are sourced from outside the household (purchased). The household needs to earn enough income to enable it to purchase all other items. To achieve that, the household has two options; either to produce maize in excess of the amount required for household consumption and the surplus maize production can be sold to generate sufficient income to purchase other food items or to produce a

[5] *Without implicating them, the advice of Danhausser and Lategan (Department of Human Nutrition, University of the Free State) in this regard is acknowledged.*

combination of the available crops (maize, sunflower and beans). Alternatively, the maize production should at least be enough to meet the household demand for maize meal. The next question is to determine how much maize grain will be required to produce the daily requirement of 400g per adult person. Assuming, on average, a processing loss of 30 percent (Hoddinott, 1999) in processing maize grain to maize meal, the amount of maize grain required to produce 400g is 520g. This means that for an average household of 3 adult equivalents, the maize grain required totals 0.56 tons per year. Households should thus at least produce 0.60 tons of maize grain to meet their yearly maize meal requirement.

Having calculated required maize grain, the income sufficient to obtain the required quantities of the other food items was calculated. The total income required per adult equivalent per year was determined to be R3,314, and for the household was R9,811. Assuming that the household was to purchase the required maize grain, then they would require an extra R319 (at 1999/2000 prices of maize grain) which makes the required income to meet food needs to be R10,131. This amount and the total income from social grants were used to determine the minimum farm size in the same way as was done with the income approach. The calculated areas of land for each technique (and approach) are presented in Table 3.

Table 3: Minimum areas of land required to ensure food security for an average household in the study area for different production techniques

Technique*	Minimum area based on income requirement (ha)	Minimum area based on caloric requirement (ha)
CON	14.49	8.45
BbBr	5.18	3.02
ObBr	4.87	2.84
ObOr	3.64	2.12
SbOr	3.51	2.05
SbSr	3.37	1.97
ObSr	3.21	1.87

Note: *CON* is conventional production, BbBr is mulch bare basins and bare runoff area, ObBr is organic mulch in the basins and bare runoff area, ObOr is organic mulch in the basins and organic mulch in the runoff area, SbOr is stone mulch in the basin and organic mulch in the runoff area, SbSr is stone mulch in the basins and runoff area, and ObSr is organic mulch in the basins and stone mulch in the runoff area.

The minimum areas of land required to achieve household food/income security vary between the conventional and *IRWH* techniques and between the two approaches (Table 3). The difference between the production techniques was however expected since they reflect the difference in productivity of the techniques. In the income approach, *CON* requires a minimum area of about 14.5 ha compared to about 3.2 ha for the *ObSr* technique. There is a sharp decrease in area from *CON* to *BbBr*, the simplest *IRWH* technique. The same trend is also shown in the caloric requirement approach, where *CON* requires 8.5 ha compared to *BbBr*'s 3.0, a decrease of 5.5 ha as opposed to 9.3 ha under the income approach for the two techniques. The differences in the two approaches are drastic, even though one would have expected the differences not to be so big.

One possible explanation for the differences might be attributed to the figure used as the monthly income requirement for an adult equivalent. The value used is the poverty line (May, 1998) which is assumed to cater for all the basic needs (food, shelter and clothes) whereas in the caloric requirement approach, only the food component is catered for. This therefore might explain the differences in the areas of land required. Another possible explanation is that the calculation of the daily caloric requirement used an average value (2500kcal).

The calculations above were integrated to form a simulation model that can be used as an extension tool. The model allows the user to specify the available land, household composition, input and output prices, a preferred crop mix and calculates the farm income based on the gross margins per crop as well as the minimum area of land required to meet household food/income security. Figure 1 presents the input and output page of the model which serves as both the input and output section of the model.

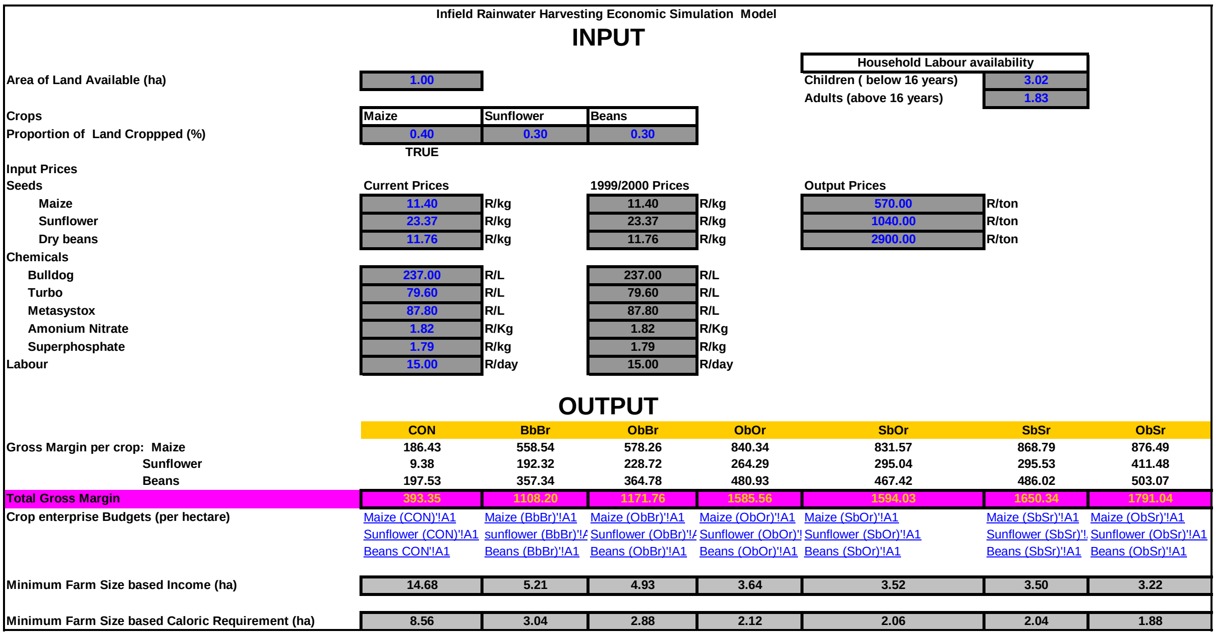

Figure 1: The input and output page of the *IRWH* Economic Simulation model (IESIM)

6. Conclusions and recommendations

The paper has shown that the *IRWH* techniques reduced considerably the amount of land to be cultivated to enable an average household to meet its food requirements using the conventional methods. But the minimum areas vary between the two approaches that were used in the calculation. The caloric approach gave smaller values than the income requirement approach because income is over other needs than food.

Under conventional production and using the income approach, an average farm household in the study area will require about 15 ha of land to be able to meet income security. This value reduces to 5 ha by moving to the least productive *IRWH* technique (*BbBr*) and reduces further to 3 ha when using the most productive *IRWH* technique (*ObSr*). When using the caloric approach the movements from 8 ha to 3 ha and 1.9 ha for the conventional, *BbBr* and *ObSr* techniques, respectively. The methodology is finally built into a computer simulation model that can be used to determine the minimum area of land for any given household when the required inputs are specified.

The results of this analysis should be used cautiously as they are indicative and not prescriptive and they provide a starting point for further analysis of the required minimum area of land. If it is assumed that the household has other means to acquire income for non-food household income, the caloric requirement criteria will be more relevant but the income approach will be important if all household needs are to be provided for by crop production. Another area that might need further research is the impact of the removal of social grants. Social grants and remittances make up more than half of the income required; their removal is likely to push up the land requirements by almost the same percentage as their contribution to household income. The estimated minimum area of land may prove very high and most probably not achievable, and under the current conditions of land scarcity there might be a preference towards the more costly *IRWH* techniques. Based on the above, it is evident that the farmers need some sort of institutional support if the *IRWH* techniques are to be sustainable. This is evidenced by the important role that the social grants play in the household livelihoods in the study area.

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References

Aliber M (2003). Chronic poverty in South Africa: Incidence, causes and policies. *World Development* 31(3):473-490.

Bickel G, Nord M, Price C, Hamilton W & Cook J (2000). *Guide to measuring food security, revised 2000.* US Department of Agriculture, Food and Nutrition Service, Alexandria VA, USA.

Botha JJ, Van Staden PP, Van Rensburg JJ, Hensley M & Macheli MS (2001). *Water conservation techniques on small plots in semi-arid areas to enhance rainfall use efficiency, food security, and sustainable crop production*. Agricultural Research Council - Institute for Soil, Climate and Water (Glen), Second Progress Report to the Water Research Commission, Unpublished.

Danhausser A (2003). *Personal Communication.* Department of Human Nutrition, University of the Free State, South Africa.

Directorate Agricultural Statistics (2002). *Abstract of Agricultural Statistics*. National Department of Agriculture, Pretoria, South Africa.

Food and Agricultural Organisation (FAO) (1990). *An international action programme on water and sustainable agricultural development*. FAO, Rome.

Fox P & Rockstrom J (2003). Supplemental irrigation for a dry spell mitigation of rain fed agriculture in the Sahel. *Agricultural Water Management* 61:29-50.

Free State Province (FSP)/World Bank (1997). *Free State mission on rural investment: action programme for the creation of sustainable livelihoods in the rural and peri-urban economy of the Free State: 1996-1997*. Department of Agriculture, Rural Strategy Unit, Glen-Free State Province, South Africa.

Hensley M, Botha JJ, Anderson JJ, Van Staden PP & Du Toit A (2000). *Optimizing rainfall use efficiency for developing farmers with limited access to irrigation water: Report to the Water Research Commission by the ARC -Institute for Soil, Water and Climate.* WRC Report No 878/1/00.

Hoddinott J (1999). *Choosing outcome indicators of household food security.* International Food Policy Research Institute (IFPRI), Washington DC, USA.

James W & Schofield E (1990). *Human energy requirements: A manual for planners and nutritionists.* Oxford University Press, Oxford, UK.

Kundhlande G, Groenewald DG, Baiphethi MN, Viljoen MF, Botha JJ, Van Rensburg LD & Anderson JJ (2004). *Socio-economic impact study of water conservation techniques in semi-arid areas.* WRC Report No 1267/1/04.

Lategan R (2003). *Personal Communication*. Department of Human Nutrition, University of the Free State, South Africa.

May J (ed) (1998). *Poverty and inequality in South Africa*. A report prepared for the Office of the Executive Deputy President and the Interministerial Committee for Poverty and Inequality. <http://www.gov.za/reports/1998/poverty>.

National Department of Agriculture (NDA) (1998). *Agricultural policy in South Africa: A discussion document.* Ministry of Agriculture and Land Affairs, Pretoria, South Africa.

National Department of Agriculture (NDA) (2001). *The strategic plan for South African agriculture*. National Department of Agriculture, Pretoria, South Africa.

Ortman G & Machethe C (2003). *Problems and opportunities in South African agriculture*. In: Niewoudt L & Groenewald J (eds), The challenge of change: Agriculture, land and the South African economy. University of Natal Press, Pietermaritzburg, South Africa.

Parr JF, Stewart BA, Hornick SB & Singh RP (1990). *Improving the sustainability of dryland farming systems: A global perspective.* In: Singh RP, Parr JF & Stewart BA (eds), Advances in soil science. Dryland Agriculture Strategies for Sustainability, Volume 13, New York, pp 1-8.

Smil V (1994). How many people can the earth feed? *Population and Development Review* 20:255-292.

Vink N & Kirsten J (2003). *Agriculture in the national economy*. In: Niewoudt L & Groenewald J (eds), The challenge of change: Agriculture, land and the South African economy. University of Natal Press, Pietermaritzburg, South Africa.

Weibe K (2001). *Natural resources, agricultural productivity and food security.* In: Issues in food security, Agriculture Information Bulletin Number 765(3), April 2001. United States Department of Agriculture: Economic Research Service, Washington DC, USA.