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An assessment of socio-economic potential for Rain Water Harvesting (RWH) in semi-arid Bobirwa Sub-district of Eastern Botswana

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ABSTRACT

This study assessed the socio-economic potential of the Rain Water Harvesting (RWH) techniques for crop production in the semi-arid area of Bobirwa Sub-district, Botswana. The main methods used to collect the data were the Participatory Rural Appraisal (PRA) approaches and researcher-farmer managed field experimentation. The data collected included the constraints to crop production and available ways of conserving soil moisture in the study area. Viability, acceptance and perception of farmers towards RWH technologies in the Sub-district were also assessed. Constraints faced by farmers in arable farming were identified as low and unreliable rainfall, pests and diseases and lack of farm implements (ranked in order of severity). Researcher-farmer managed trials were carried out with various catchment area sizes against a cropped area of 25 m^2. Catchment area sizes were 25m^2, 50m^2, 75m^2 and no catchment, resulting in catchment area to cropped area ratios of 1:1, 2:1 3: 1 and 0:1 (a control plot). Randomized Block Design (RBD) with two replicates in each village was used. Soil moisture content results were analyzed using Statistical Analysis Software (SAS Version 9.2), two way Analysis of Variance (ANOVA), at 5% level of confidence using Duncan's comparison method. Gross margins were calculated as the difference between the cost of production and income from the production. Openstat software was used to analyze the gross margins using Scheffes' comparison at alpha = 0.05. At the end of the trials period, a questionnaire was administered to the selected farmers in order to draw farmer's perception towards the technology. The results showed that a catchment area to cropped area ratio of 3:1 had significantly higher soil moisture storage (for improved crop growth) compared to 0:1, 1:1 and 2:1 ratios in each village. In the analysis of gross margins, a catchment area to cropped area ratio of 3:1 had a significantly higher gross margin (P= 0.885) of maize compared to 0:1, 1:1 and 2:1. Farmers' perception interviews showed that farmers had positive views towards the adoption of the RWH technologies. Over 75% of the farmers showed interest towards acceptance and adoption of RWH technologies.

Key words: Farmers' perception to RWH, gross margins, micro–RWH technologies, soil moisture

RÉSUMÉ

Cette étude a évalué le potentiel socio-économique des techniques de collecte d'eaux de pluie (RWH) pour la production agricole dans la zone semi-aride du sous-district de Bobirwa au Botswana. Les principales méthodes utilisées pour la collecte de données sont les approches d'évaluation rurale participative (PRA) et des essais agricoles conduits par collaboration chercheurs-agriculteurs. Les données ont été recueillies sur les contraintes liées à la production des cultures et les moyens de conservation de l'humidité du sol disponibles dans la zone d'étude. La viabilité, l'acceptation et la perception des agriculteurs à l'égard des technologies de RWH dans le sous-district ont été évaluées. Les contraintes rencontrées par les agriculteurs dans les cultures labourées sont les faibles précipitations et peu fiables, les ravageurs et maladies des cultures et le manque d'outils agricoles (classés par ordre de sévérité). Les essais conduits par la collaboration chercheurs-agriculteurs ont été effectués avec des bassins de différentes tailles contre une superficie cultivée de 25 m^2. Les taille des bassins étaient 25 m^2, 50 m^2, 75 m^2 et sans aucun bassin versant, ce qui équivaut à des ratios 1: 1, 2: 1 3: 1 et 0: 1 (une parcelle témoin) de rapports de surface de bassin à surface cultivée. Des blocs complétement aléatoires (RBD) avec deux répétitions dans chaque village ont été utilisés. Les résultats de la teneur en eau du sol ont été analysés à l'aide du logiciel d'analyse

statistique (SAS Version 9.2) ; analyse de la variance à deux critères (ANOVA) avec un dégrée de confiance de 5% en utilisant la méthode de comparaison de Duncan. Les marges brutes ont été calculées comme la différence entre le coût de production et les revenus de production. Le logiciel Openstat a été utilisé pour analyser les marges brutes en utilisant la comparaison de Scheffes avec alpha = 0,05. A la fin de la période des essais, un questionnaire a été administré aux agriculteurs sélectionnés afin d'établir la perception des agriculteurs à l'égard de la technologie. Les résultats ont montré que le ratio 3: 1 de rapport surface de bassin à surface cultivée avait significativement un taux plus élevé de rétention d'humidité du sol (pour une meilleure croissance des cultures) par rapport aux ratios de 0: 1, 1: 1 et 2: 1 dans chaque village. Dans l'analyse des marges brutes, le ratio 3: 1 de rapport surface de bassin à surface cultivée avait donné une marge brute significativement plus élevée (P = 0,885) de maïs comparé aux ratios de 0: 1, 1: 1 et 2: 1. Les enquêtes sur la perception des agriculteurs ont montré que les agriculteurs avaient des opinions positives à l'égard de l'adoption des technologies de RWH. Plus de 75% des agriculteurs ont manifesté leur intérêt vers l'acceptation et l'adoption des technologies de RWH.

Mots clés: la perception des agriculteurs sur RWH, marges brutes, micro-RWH technologies, humidité du sol

INTRODUCTION

Agriculture plays an important role in food production, income generation as well as in employment creation for many people, particularly in the rural areas of Botswana. The country has semi-arid climate with the average annual rainfall of 250-650 mm received in the summer months of October to April. The pattern of rainfall is mono-modal and unreliable hence arable production fluctuates and cannot be depended upon (Government of Botswana, 2000).

To maximize production under these prevailing climatic conditions, it is thus crucial that every effort be made to conserve and efficiently utilize the scarce rain water. Better management of rain water where it falls, apart from enhancing plant production, is also necessary in the protection of the environment. This is because poor management allows wasteful runoff to occur, causing erosion, downstream flooding and siltation. To mitigate the effects of water shortage subsistence farmers are turning to yield improving measures such as water harvesting (Smith, 2011). Rainwater Water Harvesting (RWH) can be defined in various ways, however, a basic definition is that given by Myers (1975) as "any system that encompasses methods for collecting, concentrating and storing various forms of runoff for various purposes." Bisoyi (2006) defines rainwater harvesting (RWH) as "the collection of rain falling on earth surfaces for beneficial uses before it drains away as run-off."

When the collected runoff water is diverted directly into the cropped area during the rainfall event, the technique is called runoff farming water harvesting or generally as Rain Water Harvesting (RWH). The quantity of runoff exceeds the infiltration capacity of the soil. Therefore, ridges, borders, or dikes are placed around the cropped area to retain the water on the soil surface. A further differentiation is based on the size of the water harvesting system (Oweis *et al.*, 1999). Size governs the type of crops that can be grown. Micro-catchment RWH systems are primarily used for covering small areas (e.g. trees, grain crops, etc.) and are characterized by a relatively small runoff producing catchment. Mini-catchment RWH systems are primarily used for row crops or strips of annual crops, and the runoff producing catchment is a long strip. Macro-catchment RWH refers to large-scale rain water harvesting.

Rain water harvesting techniques are of great importance in improving yields and farmers' income. Research conducted by UNEP/SEI (2009) in India showed that the total average net income of farmers using rain water harvesting techniques was more as compared to that of those without this technology. It was also found that the application of this technology resulted in higher labour costs as compared to where the rain water harvesting was not in use. The introduction and adoption of RWH systems or technologies in the semi-arid areas of Tanzania has significantly reduced the constraint of soil moisture to crop production (Hatibu *et al.*, 1999). Rain water harvesting for crop production has a potential for poverty reduction by giving impressive returns to labour and even during below average rainfall seasons (Mutabazi *et al.*, 2009). RWH has also resulted in livestock increase per household, partly as more fodder is available in addition to reduced erosion through conservation tillage and soil bunds construction and its effects have not affected the water supplies downstream (Stockholm Environment Institute, 2009). RWH has drawn increased attention in many parts of the world as an economic and sustainable water source for both drinking and non-portable use (Coker *et al.*, 2013).

In Botswana, macro-catchment RWH (or ex-situ RWH) is used extensively by farmers. Examples of common ex-situ methods used include sand rivers,

hafirs and earth dams. Rain water is collected in these structures for use outside the rainy season (Burnclark, 2010). Micro-RWH (including in-situ method), which markedly increases soil moisture storage for improved crop growth, is rarely used (Burnclark, 2010). Information on micro-catchment RWH is also scanty. Comparison of arable and pastoral farming in the Bobirwa Sub-district (study area), with an annual average rainfall of 300-400 mm, shows that arable farming has been experiencing persistent low crop yields (SADC Secretariat, 2008). Pastoral farming has also depreciated in the area due to drought and the recent outbreak of Foot and Mouth Disease (FMD). There is, therefore, a need to assess the socio-economic potential of micro-RWH in the study area with the ultimate goal of increasing sustainability of crop production through more effective management of rain water.

The objectives of this study were to: (1) assess awareness of farmers on RWH techniques; (2) assess RWH potential of different catchment area - cropped area ratios; (3) determine farm income improvement ability of RWH; and (4) assess perception and acceptance of farmers on RWH techniques in the semiarid Bobirwa Sub-district of eastern Botswana.

MATERIALS AND METHODS

Bobirwa Sub-district (Figure 1) is made up of a number of villages from which only 3 villages were selected, namely, Mathathane, Motlhabaneng and Tsetsebjwe. The soil types in these villages are classified as Chromic luvisol (Mathathane), Calcic cambisol (Motlhabaneng) and Ferric luvisol (Tsetsebjwe), (Kayombo *et al.*, 2005). The present study focused on micro catchment RWH systems.

Participatory Rural Appraisal (PRA) was used to obtain necessary information on farmers' awareness and perception of the RWH technologies. The purpose of the PRA was to describe the farming systems and agronomic practices in relation to soil moisture conservation techniques. The PRA was conducted in two phases.

Phase 1 involved village visits aimed at obtaining the general picture of organization of local government and agriculture in the selected villages and major problems faced by farmers in the Sub-district. Discussions with farmers were conducted in order to obtain information on the prevailing farming systems in the Sub-district. Farmers were interviewed in a workshop as a larger group that included all those who attended the

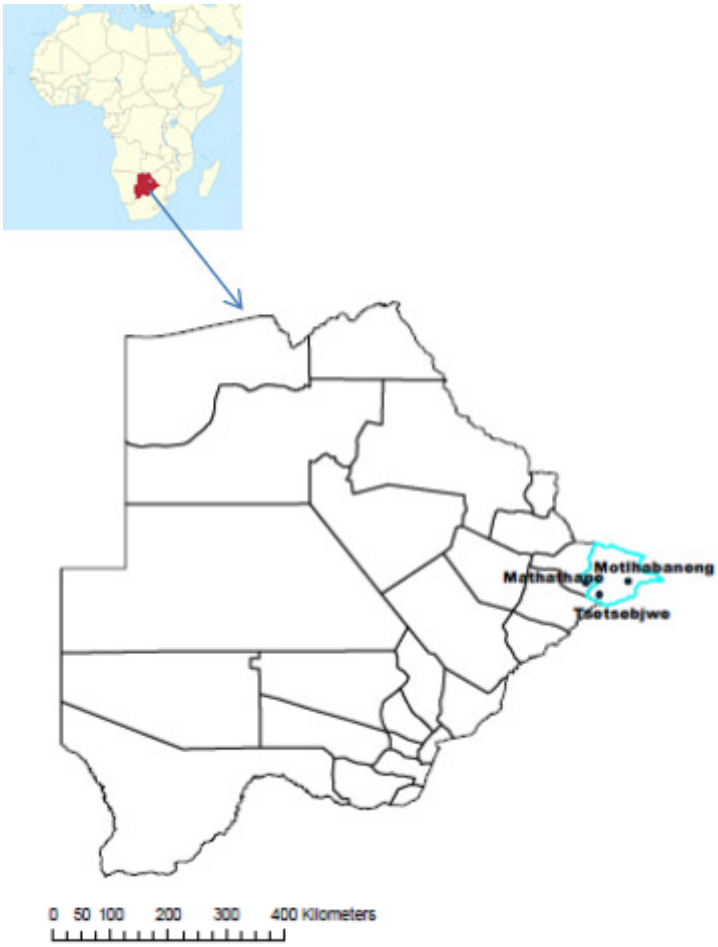

Figure 1: Location of Bobirwa Sub-district in Botswana

workshop and then smaller groups of about 10 people were formed by random selection of people. From these smaller groups, individuals were selected for further interviews.

Phase II involved in-depth discussions with village leadership, social workers and agricultural extension officers. The discussions emphasized much on soil moisture conservation techniques. From each village five (5) farmers were identified for field trials. The selection was based on the willingness of the farmer to engage on the technique, the availability of land and other resources. The monitoring scheme (off season activities) was also used to gather information regularly for a defined period through administration of a structured questionnaire to the selected farmers.

Based on the outcome of PRA and socio-economic monitoring, field trial plots were designed and laid out to test crop response to RWH. The field trial plots were managed by farmers themselves except in data collection. Cropped plots of 5 x 5 m (25 m^2) were laid on selected farmers' fields. Completely Randomized Design (CRD) with two replicates was used. Maize (*Zea mays*) variety SR52 was used as the test crop in the study because it was the most common planted crop in the area. Runoff was directed to the plots from different sizes of catchment areas. The ratios of catchment area to cropped area ranged from 1:1 to 3:1, that is the catchment areas measured 25m^2, 50 m^2, and 75 m^2. The catchment areas were located up the slope (on the hill side) of the cultivated area so that water and nutrients could flow easily to the cropped area. All catchment (uncultivated) areas were debushed and mowed to reduce water infiltration during the rainy season. Since the field trial plots were laid out in areas that had been used yearly for cultivation, the areas were already cleared in the previous seasons; therefore no costs were incurred for land clearing. Slopes were also measured in each location where these plots were made. Soil moisture was measured gravimetrically in the 0-10 cm layer a month after the end of rainy season. Soil moisture data was analyzed using Statistical Analysis Software (SAS version 9.2) computing two way Analysis of Variance (ANOVA), Duncan's multiple range test at 5% confidence level. Comparison of treatment levels was done across the villages.

The gross margin was calculated as the difference between gross output and variable costs. Gross margin was used to determine how much each farm enterprise contributed to the total farm profits. The value of output (gross revenue) was determined by measuring the actual output produced in the different trials and multiplying by the prevailing market price. The variable costs were recorded for variable inputs used in each trial. The variable inputs included: seeds, fuel, transport and labour used to perform different activities in each trial. In order to determine as to whether there were significant differences between treatments the calculated gross margins were analyzed using Openstat software, two way ANOVA applying Scheffe's contrasts among pairs of means for each treatment level and among villages at 5% level of confidence.

At the end of field trial period, the farmers were interviewed to obtain their views and perception on the technology. The interview used the Likert scale type of questions. The Likert item consisted of a positive statement about some feeling, belief or opinion and a series of responses representing a number of potential responses, from "strongly agree" to "strongly disagree" (Aaker and Day, 1998). A table was used in analysis of the Likert items. Perception analysis helped in assessing the acceptance of RWH technology by farmers.

RESULTS AND DISCUSSION

Awareness of farmers on RWH

Information obtained from the PRA workshop indicated that there had been a decline in production in Bobirwa Sub-district. The major crop production constraints perceived by farmers in the study area and their level of severity are shown in Figure 2. According to 75% of farmers who were interviewed, the following factors had a role to play in crop production: shortage of land, prevalence of pests and weeds, shortage of machinery and labour, and low and unreliable rainfall, in order of increasing importance. With these low rains in the area, the chances of crop failure are increased for a commonly grown crop such as maize. Any water deficit during critical growth stages is a major constraint in crop production leading to a gap between actual output and potential output (Fox and Röckstrom, 2003). Water deficit during productivity stage can lead to severe loss in yield (Khalili *et al*., 2013).

Seventy five percent of farmers had no idea on RWH technologies. Farmers in the study area are, however, familiar with in-situ soil moisture conservation methods such as cultivation across the slope though they do not put such into practice. Some of the reasons cited by farmers are that they are accustomed to traditional ways of farming hence it is difficult to change.

Monitoring of off-season activities revealed that farmers do engage in different social activities outside their farming cycle. These include attending "motshelo" which is a traditional fundraising activity, kgotla meetings, funerals, weddings and visiting friends and relatives. Field preparations such as clearing, debushing and fencing may also be part of the off-season activities but they are mainly done when the cropping season approaches. Mostly, this is the period when farmers'

concentration is towards the livestock. Livestock management activities such as branding, vaccination and dehorning are the common activities in the farmer's calendar during this off-season.

RWH potential of various catchment – cropped area ratios

Soil moisture analysis was used to assess the RWH potential of various catchment - cropped area ratios. The results of the soil moisture analysis depict no significant difference for all treatment plots across the three villages (Table 1). The differences in physical and chemical properties of the soils in Bobirwa Sub-district are generally small (Kayombo *et al*., 2005). This small difference in soil properties contributed to the treatments having no significant difference across the villages. The range of slopes (0.004 to 1.78%) also did not have any significant moderating influence on soil moisture content.

The only observed significant difference of the soil moisture analysis was between 0:1 - 2:1 as a group and 3:1 across all the villages (Table 2). This catchment area to cropped area ratio of 3:1 had significantly higher soil moisture storage for improved crop growth by 45% compared to the 0:1 ratio. This result is of particular importance to the suitable catchment size of a RWH system for crop growth in semiarid areas. The catchment area (compared to the cropped portion) must be large enough to store soil moisture that can be used by the growing crop even up to a month after the seizure of the rainy season. These results are in agreement with those of Hatibu *et al.* (1999) which showed, in a semiarid zone of Tanzania, that there was an increase of 17% in maize yield for a catchment – cropped area ratio of 4:1 over the control (0:1), during *Masika* (long rains), while the increase during *Vuli* (short rains) for the same catchment – cropped area ratio was 152%.

Benefits of RWH technologies

General comparisons among treatments, according to Scheffe's contrasts (Table 3), show that the gross margins of treatments 0:1, 1:1 and 2:1 did not significantly differ from each other. A significant difference in gross margins was, however, observed

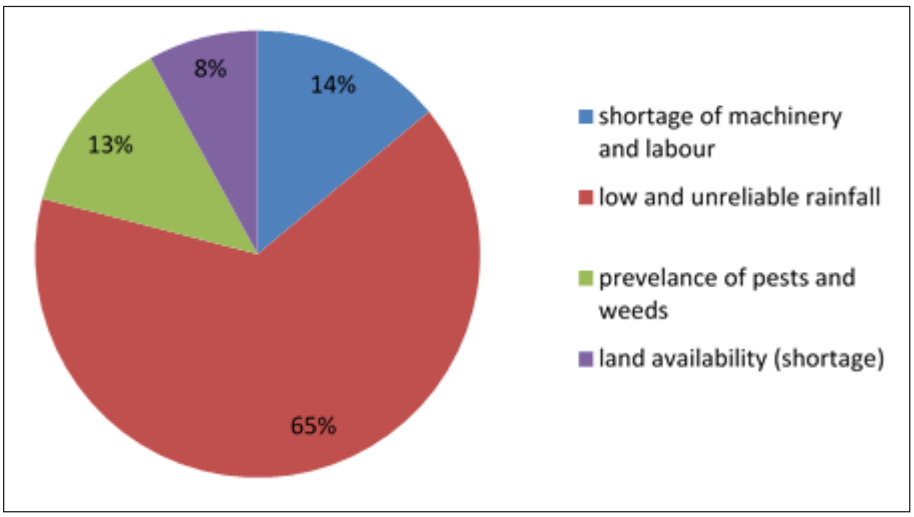

Figure 2: Main constraints to crop production in Bobirwa Sub-district

Table 1: Separation of soil moisture means across villages for various RWH techniques using Duncan Grouping

Village	Major soil type	Mean volumetric soil moistures (g/cm3)
Motlhabaneng	Chromic luvisol	3.8500 a
Mathathane	Calcic cambisol	30250 a
Tsetsebjwe	Ferric luvisol	3.0125 a

Note: Villages with the same letter grouping are not significantly different.

Table 2: Separation of soil moisture means for different treatments using Duncan Grouping

Catchment- cropped area ratio	Mean volumetric soil moistures (g/cm^3)
3:1	4.4667 a
2:1	3.4667 a, b
1:1	2.8333 a, b
0:1	2.4167 b

Note: Catchment cropped area ratios with the same letter grouping are not significantly different.

Table 3: Scheffe's contrasts among pairs of means of gross margins among treatments

		Scheffe contrasts among pairs of means. alpha selected = 0.05			
Treatment vs Treatment		Difference	Statistic value	Scheffe critical	Significantly different?
0:1	1:1	-7.33	2.68	3.049	No
0:1	2:1	-7.83	2.86	3.049	No
0:1	3:1	-15.00	5.49	3.049	Yes
1:1	2:1	-0.50	0.18	3.049	No
1:1	3:1	-7.67	2.80	3.049	No
2:1	3:1	-7.17	2.62	3.049	No

Table 4: Farmers' perception towards RWH technologies in Bobirwa Sub-District

Statement/ Question	Motlhabaneng	Mathathane	Tsetsebjwe	Average perception
1. Have full knowledge of RWH	2	2	2	2
2. I have experience of RWH techniques	2	2	2	2
3. RWH technologies can be beneficial to me as a farmer	1	2	2	2
4. RWH technologies can be advantageous as it can help in increase crop yield	5	2	2	3
5. RWH technologies can be used to prevent soil erosion	2	3	2	3
6. RWH technologies can be disadvantageous as it is labour intensive	3	2	3	2
7. Lack of finance is the most limiting factor to adoption of RWH	2	3	3	3
8. Lack of farm implements and finances are the limiting factors for me to employ RWH technologies	3	4	4	4
9. The slope of my land is steep enough (2-5%) to allow diversion of runoff to the cropped area	3	2	2	2
10. Land availability is not a problem or hindrance for me to use RWH technologies	3	3	1	2
11. Having tried RWH techniques in my farm, I will adopt or continue using the technology in future	2	2	2	2

Key: 1 - strongly agree; 2 – agree; 3 – neutral; 4 – disagree and 5 – strongly disagree

NOTE: General perception was obtained by summation of response scores divided by number of respondents (Brown, 1988).

between the treatments 3:1 and 0:1. This catchment area to cropped area ratio of 3:1 significantly increased the gross margin of maize by 44% compared to the 0:1 ratio. This underscores the role played by stored soil moisture of the 3:1 treatment for improving crop growth. These results are in agreement with those of Hatibu *et al.* (2006) in Tanzania, who found that water harvesting increased the economic returns to both land and labor, as water harvesting allowed farmers to grow rice and vegetables because these commodities have greater economic value than the traditional crops of maize and sorghum hence helping in poverty alleviation.

Farmers' perception of RWH technology

Table 4 shows the responses of farmers to Likert scale questions on their perception towards RWH technologies in Bobirwa sub district.

Table 4 shows that most of the farmers responded positively towards the technology by providing "agree to strongly agree" answers to the administered questionnaire. Compared to their responses in the PRA workshop, farmers responded with "Agree" towards having knowledge of RWH. This means that the awareness workshop and the farmer-trials helped in bridging the knowledge gap. According to the farmers the technology was beneficial to them as their responses ranged from "agree to strongly agree".

Farmers' perception showed that they understood the methods of RWH and appreciated its benefits to crop production. They even indicated that land, farm implements and finances were available for implementation of these RWH techniques (Table 4). Despite additional labour costs to their farming system as a result of introducing RWH, farmers were optimistic on adopting the technology. They showed positive attitude towards adopting the technology in the future by responding with "agree".

CONCLUSIONS

This study assessed the socio-economic potential of RWH technologies in Bobirwa Sub district. The assessment was informed by critical factors such as farmers' perceptions towards the technology, availability of assets, machinery and finances to fund the technology. Viability and acceptance of RWH in the study site were also key areas of concern.

The following conclusions are drawn from the study:

(1) Workshops and researcher-farmer managed trials markedly raised farmers' knowledge, confidence and awareness on RWH technologies;

(2) A catchment area to cropped area ratio of 3:1 had a significantly higher soil moisture storage for improved crop growth by 45% compared to 0:1 ratio across the three villages;

(3) A catchment area to cropped area ratio of 3:1 significantly increased the gross margin of maize by 44% compared to 0:1 ratio across the three villages;

(4) Over 75 % of the farmers showed interest towards acceptance and adoption of RWH technologies.

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STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

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