CHAPTER I
INTRODUCTION

1.1 General Background

Flow of adequate food supplies to meet rising demand is increasingly threatened by climate change and land degradation due to soil erosion. According to the United Nations, the present world population stands at about 6.3 billion and with an average annual growth rate of 1.3 percent, this population is estimated to reach 8 billion in 2025 (United Nations Population Reference Bureau, 2004). Majority of the world’s population lives in the emerging and least developed countries. The increase in numbers of mouths to be fed and the improving diet requirement is increasing the food demands. The main challenge in this regard remains how to double the global food production in general and in Asia and Africa in particular in the next 25 years. Though total area in the world is 13,390 Mha, very little of the land surface, nearly 1500 Mha (11 percent) is currently used for agriculture. The potentially cultivable land is estimated at about 3000 Mha. The land which is fertile and suitable for cultivation had already been brought under the plough. The land which can be brought into production will not be as fertile and productive as the land currently under cultivation. Therefore, a doubling of production can be achieved only by suitable strategies of soil and water conservation and water management and by improving soil fertility. The total irrigated area in the world is about 260 Mha or about 17 percent of the cultivated area, of which two-thirds is in the developing countries. Such lands are marginal, spread over poorly productive environments and with meagre production capabilities, thus limiting the scope for increasing production. Water conservation techniques involving and \textit{in-situ} moisture conservation techniques and engineering measures need to be emphasized for feasible adoption in rainfed agriculture to increase land productivity.
In sub-Saharan Africa, over 60 percent of the population depends on rain-based rural economies, generating about 30 to 40 percent of the regions’ GDP (World Bank, 1997). Rain-fed agriculture is practiced on approximately 95 percent of agricultural land, with only 5 percent under irrigation (Rockstrom et al., 2002). However in this part of the world, yields from rain-fed agriculture are low, oscillating around 1 t ha⁻¹ (Rockstrom, 2001). Many researchers suggest that the low productivity in rain-fed agriculture is more due to sub-optimal performance related to management aspects than to low physical potential. For instance, Bennie et al. (1994) reported that in many arid and semi-arid areas between 60 and 85 percent of the rainfall evaporates from the soil surface before making any contribution to production.

1.2 Country description

1.2.1 Geography and population

Rwanda is a small, mountainous, landlocked and densely populated Central African country, generally known as “a land of 1,000 hills”. Rwanda is located in the heart of Africa within the Great Lakes region. The total surface area is 26,338 km sq. of which 14,000 km² are arable of which 60 to 70 percent is cultivated.; Rwanda lies between 10° 04’ and of 2°45’ of latitude south and between 28°53’ and 30°53’ of longitude East. It is estimated to be 120 km south of the equator, and 1,100 km from the Indian Ocean and 2,000 km from the Atlantic Ocean. The bordering Countries are: Tanzania in the East, Burundi in the South, the Democratic Republic of Congo to the West and Uganda to the North.

Rwanda has uneven relief offering a landscape of hillsides with steep hillsides which exposes it to massive soil erosion. The altitude of Rwanda is between 900 m in the Southwest (Bugarama) and 4,500 m in the Northwest (Chain of volcanoes). One distinguishes usually 5 zones: the valley of Rusizi with a height of about 900 m in the Southwest, the chain of volcanoes
in the Northwest among which volcanoes Kalisimbi (4,507 m), Muhabura (4,127 m), Biseoke or Bushokoro (3,711 m), Sabyinyo (3,631 m) and Gahinga (3,474 m on Rwanda side, Crest of Congo - Nile whose height is between 1,800 and 3,000 m. The central plateau is with average altitude varying from 1,500 to 1,900 m. The Eastern part of Rwanda is with much lower altitude down from 1,500 to 1,000 m.

Rwanda has a hydrographic network characterized by abundance of water from rivers and lakes. The rivers of Rwanda are divided between two hydrographic basins known as Congo and Nile bassin. The soils of Rwanda come from the physicochemical deterioration of the schistose, quartz, gneissic, granite and volcanic rocks which constitute the geology of the country. Its pedology is characterized by six types of soils: the soils derived from the schistose formations, sandstone and quartzite, the soils derived from granite and gneiss occupy approximately the soils derived from the intrusive basic rock cover hardly 10 percent of the territory; soils derived from recent volcanic materials, soils derived from old volcanic materials; the alluvial soils and colluvionnaries characterized by the swamps of Rwanda.

The population census of 2002 estimated the population at 8,128,553 inhabitants out of which 3,879,448 were men and 4,249,105 were women. The population today is estimated at 8,500,000 inhabitants and the annual population growth is 1.2 percent and the active population is 76.8 percent of the total population. Its population density increased from 99 per km$^2$ in 1962 to 309 per km$^2$ in 2002. Out of the total population of 8.1 million in 2002, 83 percent lived in rural areas and 36 percent was engaged in farming. The rate of literacy is 58.8 percent with a variation between the level of literacy of women (53.8 percent) and that of men (65 percent).

Rwanda is a poor country and land is scarce, with only 0.65 ha of suitable farmland per household. The country is facing with increasing soil fertility depletion, erosion and lack of
enough soil moisture during dry season due to steep landscape, continuous cultivation and high but not well distributed rainfall. Rwanda needs to produce more and more food with a view of meeting the ever increasing population. As of today Rwanda produces only 20 per cent of the market demand and only 0.10 per cent of this production is being exported. There is a need to have much attention in the areas of soil loss, organic manure, and soil fertility and supplemental irrigation in the undulating topography of Rwanda. However, published work since 1995 scarcely refers to the early studies that provide basic information for understanding the soil moisture depletion pattern need of irrigation and its impact on sustainable productivity. This caused researchers to focus its attention in the present study of soil moisture conservation and supplemental irrigation.

The Government of Rwanda in its Vision 2020 and its EDPRS (Economic Development and Poverty Reduction Strategy) considers agriculture as an engine that drives the economy. It is through commercialized and professional agriculture that aims to fulfill the objectives of poverty reduction and food security as well as export earnings and industrialization. This calls upon increased and sustained productivity through farmer-participatory land care, water harvesting and intensified irrigation in the hillsides (Rwanda, 2007). The EDPRS builds on the Strategic Plan for the Transformation of Agriculture (SPAT) and emphasizes support to the agricultural sector to transform and modernise it.

Agriculture is the leading sector in the national economy of Rwanda, accounting for about 42 percent of GDP, while contributing almost 35 percent of export earnings and employing 90 percent of the labour force. Rwanda being an agrarian country is endowed with irrigation potential and agro-ecological diversities favourable for the growing of various crops. Agriculture is mainly rainfed and subject to erratic rainfall.
Irrigation is mostly carried out on about 60,000 ha of reclaimed marshlands, of which only 3 percent are rationally exploited. Hillside irrigation is not yet practised outside pilot activities. Rwanda is known as the land of 1,000 hills. Much of the country is occupied by hills and their accompanying steep slopes. In general, the area under irrigation will increase from 15,000 to 24,000 hectares, and of this, the hillside area irrigated will expand from 130 hectares to 1,100 hectares by year 2015 (MINECOFIN, 2007).
The study area is located in the outskirt of Kigali, the capital city of Rwanda. Figure 1 shows the location of Kigali in the administrative map of Rwanda. The area is recognized as the hottest and driest part of the country. In spite of the fairly fertile nature of the ground, water scarcity makes agriculture difficult though it is the base of the economy of rural community.

1.2.2 Land and Agricultural Production status

Eleven per cent (2,849 km²) of the country is occupied by lakes, rivers, marshes, towns, roads and built-up areas. The remainder (23,487 km²), called “green land”, can be used for crops, grazing, and natural vegetation. Rwanda green land is located into three altitude zones: low green lands of less than 1600 m altitude forms 38 percent; middle green land of altitude between 1600 - 2100 m forms 33 percent; and high green land of greater than 2100 m altitude forms 18 percent. The most relevant soil parameters for crop production in Rwanda are summarised in Table 1.

Major interventions are needed for the maintenance and improvement of soil productivity: drainage is required for the 5 percent of land; special measures for erosion control are needed on the 53 percent of the country that has slopes steeper than the 6° limit for agronomic erosion-control measures; soil amendments and nutrients are always needed, but especially on the 51 percent of soils with base saturation less than 35 percent; shallow soils (thickness < 0.5m) occupy 25 percent of the land; soil organic matter quality and, sometimes, its quantity and soil moisture holding capacity also govern crop production.
Table 1 Soils in Rwanda with some characteristics relevant for crop production

<table>
<thead>
<tr>
<th>S.No</th>
<th>Characteristics</th>
<th>Value in percent</th>
<th>Percent of total land</th>
<th>Square KM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slope class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-13</td>
<td>47</td>
<td>11,045</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14-55</td>
<td>30</td>
<td>7,013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 55</td>
<td>23</td>
<td>5,429</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Base saturation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 20</td>
<td>25</td>
<td>5,866</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20-35</td>
<td>27</td>
<td>6,224</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;35</td>
<td>45</td>
<td>10,590</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not measured (Histosols)</td>
<td>3</td>
<td>807</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Soil texture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 60 percent clay</td>
<td>10</td>
<td>2,378</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35-60 percent clay</td>
<td>70</td>
<td>16,194</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20-34 percent clay</td>
<td>17</td>
<td>4,086</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sand and Histosols</td>
<td>3</td>
<td>829</td>
<td></td>
</tr>
</tbody>
</table>

4 Soil orders

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value in percent</th>
<th>Percent of total land</th>
<th>Square KM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxisols</td>
<td></td>
<td>10</td>
<td>- 2,433</td>
</tr>
<tr>
<td>Ultisols/Oxisols</td>
<td></td>
<td>19*</td>
<td>4,549</td>
</tr>
<tr>
<td>Ultisols</td>
<td></td>
<td>33</td>
<td>7,647</td>
</tr>
<tr>
<td>Vertisols</td>
<td></td>
<td>2</td>
<td>559</td>
</tr>
<tr>
<td>Inceptosols</td>
<td></td>
<td>16</td>
<td>3,645</td>
</tr>
<tr>
<td>Entisols</td>
<td></td>
<td>17</td>
<td>3,847</td>
</tr>
<tr>
<td>Histosols</td>
<td></td>
<td>3</td>
<td>807</td>
</tr>
</tbody>
</table>

Source: MINAGRI (2008)

Table 2: Actual and potential green land use in Rwanda

<table>
<thead>
<tr>
<th>Land use</th>
<th>Actual</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Square KM</td>
</tr>
<tr>
<td>Crops</td>
<td>46</td>
<td>10,531</td>
</tr>
<tr>
<td>Grazing</td>
<td>22</td>
<td>5,095</td>
</tr>
<tr>
<td>Forests + natural reserves</td>
<td>32</td>
<td>7,339</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>22,965</td>
</tr>
</tbody>
</table>

Source: MINAGRI (2008)
1.2.3 Climate

Rwanda enjoys a moderate continental tropical climate with two dry seasons which alternate with two rainy seasons. Rwandan climate is tropical, influenced by altitude. The average temperature in the whole country is 19.5°C, with variations between 15°C and 29°C, these variations are closely linked to altitude. Temperatures in the highest mountain areas in the North-West are much lower than in the rest of the country. Annual precipitations vary between 700 mm and 1400 mm in the lowlands of the East and the West, between 1,250 mm and 1,400 mm in the central area of the plateau and 1,400 mm to 2,000 mm in the area of high altitude. The dryness, floods and the landslides are very frequent in Rwanda. The areas of East and South-Eastern experience prolonged drought while the areas of the Northern and Western part experience floods and landslides.

There are two rainy seasons alternating with dry seasons. The different seasons and climate are shown below:

Table 3 *Seasons and climatic data of Rwanda*

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Period of year</th>
<th>Sunshine hours day&lt;sup&gt;−1&lt;/sup&gt;</th>
<th>Ambient temp °C day&lt;sup&gt;−1&lt;/sup&gt;</th>
<th>Max. temp °C day&lt;sup&gt;−1&lt;/sup&gt;</th>
<th>Min. temp °C day&lt;sup&gt;−1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short rainy</td>
<td>Mid Sept to Mid December.</td>
<td>5.0 to 5.5</td>
<td>19.4 to 20.5</td>
<td>32.8</td>
<td>25.8</td>
</tr>
<tr>
<td>Long Rainy</td>
<td>March to Mid May</td>
<td>5.1 to 5.5</td>
<td>20.0 to 20.1</td>
<td>30.8</td>
<td>25.6</td>
</tr>
<tr>
<td>Short sunny</td>
<td>Mid December to February</td>
<td>5.2 to 5.5</td>
<td>19.7 to 20.5</td>
<td>33.0</td>
<td>25.8</td>
</tr>
<tr>
<td>Long sunny</td>
<td>Mid May to Mid September</td>
<td>5.5 to 7.4</td>
<td>20.0 to 21.4</td>
<td>32.8</td>
<td>26.1</td>
</tr>
</tbody>
</table>

Source: Meteorology station, Kigali
From highlands to lowlands, annual rainfall ranges from more than 2000mm to less than 1000mm. Rainfall events are erratic, especially in the eastern part of the country and drought or excess of rainfall may cause yield losses from 25 to 100 percent.

1.3 Problem definition

1.3.1 Food security

Rwanda, a sub-Saharan country does not make exception to the region’s water management problems. However the consequences are more severe in dry parts of the country. Rubirizi located in Gasobo District is among the regions that receive inadequate amount of rainfall in this country. This District has been facing prolonged period of drought since year 1998 which resulted in food insecurity and massive population movement from other regions of the country. The following figure shows the map of food security risk situation of the country in the year 2006; it may be seen that in a large part of Bugesera and other areas in eastern province were at high risk of food security. Outskirts of Kigali which represents part of drought affected areas of Rwanda.

Fig 2 Food security risk in Rwanda (FEWS Net, 2006)
To raise agriculture production in the Gasabo district, more irrigation is required but the quantity of irrigation water is extremely limited. Therefore, other sources of irrigation water have to be sought for. As it may be seen in following figure 3, the country’s dense hydrographical network of small steady rivers seems not to profit this District since they are not perrenial.

Fig 3 Hydrographical Network of Rwanda (MINITERE, 2004)

Furthermore, this District is known to be the moderately hot and dry in the country as shown in figure 4.

Fig 4 Temperature distribution in Rwanda (MINAGRI, 2006)
Rubirizi area, as well as the **Northeast** (former **Umutara** province) and the East (Northeast and southern former **Kibungo** province), is counted as one of the rainfall deficit risk zone which is characterized by frequent rainfall deficit, late rainfall onsets, early rainfall cessations and **significant** number of dry spells. The average rainfall is **around 850** mm against 1200 mm in the rest of the country (Figure 5),

![Rainfall distribution in Rwanda (MINAGRI, 2006)](image)

**Fig 5 Rainfall distribution in Rwanda (MINAGRI, 2006)**

Kigali region has problems linked to water availability that may be addressed through rainwater harvesting practices. The first step in the direction of developing and implementing water resource management through rainwater harvesting in a certain region, is the evaluation of the region’s rainwater harvesting potential (A. K. Tripathi *et al.,* 2005).

With comparison to other regions of the country, Gasabo District and Bugasera district are characterized by a dry and very warm climate resulting from absence of mountains, relatively low altitude, scarcity of rain and excessively long period of drought. The mean atmospheric
temperature varies with time but normally between 21°C and 23 °C. The maximum ranges between 26°C and 29°C, whereas the minimum remains in the order between 13° C and 15°C. Under a bimodel rainy season and flooding cycle of wetland and marshland, the cropping pattern in Rwanda is generally categorized into three cropping seasons, A, B and C, as represented below (Table 4). The cropping season starts from September and end in July in hillside, while in marsh and wetlands a cropping season ranges from June to October or next March depending on flood cycle of applicable area.

Table 4 Normal crop seasonal calendar

<table>
<thead>
<tr>
<th>Season B – Long Rains</th>
<th>Season A – Short Rains</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planting</strong></td>
<td><strong>Planting</strong></td>
</tr>
<tr>
<td>Feb       Mar       Apr   May   Jun   Jul   Aug</td>
<td>Sep       Oct       Nov    Dec   Jan</td>
</tr>
<tr>
<td>Harvesting</td>
<td>Harvesting</td>
</tr>
</tbody>
</table>

Source: REMA, 2007

These seasons, however, capriciously change both the beginning and the duration. Besides, the last 12 years (1992-2004) have been characterized by many climatic irregularities and even less favorable rainfall condition with frequent long period of drought over all the area in Kigali region and eastern province.

1.3.2 Agricultural production

Based on the reconnaissance survey and the sampling farm household survey by MINAGRI, major cultivated crops observed by the land use in the study area are summarized in table 5.
Table 5 Cultivated crops in Gasobo district

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Land use</th>
<th>Cultivated crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hillside</td>
<td>Sorghum, Maize, sweet potato, Bean, Cassava, tomato</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fruit tree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coffee, mango, Pineapple, Banana, Guava, Lemon, Avocado</td>
</tr>
<tr>
<td>2</td>
<td>Marshland, wetland</td>
<td>Sorghum, Maize, sweet potato, rice, potato, tomato,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cabbage, onion, carrot, cucumber and pumpkin</td>
</tr>
</tbody>
</table>

The crop production runs up against the problems of the climatic risks, in particular the dryness on the hills and the floods in the marshes. Moisture tolerant crops such as sorghum, cassava and sweet potato are generally cultivated in the hillside, while sensitive crops to moisture stress such as banana and vegetables are allocated in around of the hill bottom where soil moisture is relatively high compared to hillside, and irrigation practice is observed for vegetable production as well.

1.3.3 Rainwater Harvesting and erosion control practices

Rubirizi, a drought prone area due to erratic rain, the need to secure rainwater for crop production is vital; however, water harvesting measure is not widely observed in the hillside. Only a few farmers apply this practice to banana fields to trap rainwater by making ditches along the downhill feeder road. Rainwater flows into depression made around banana planting hill, and then flow into next banana plant hill by gravity. Farm pond on the hillside is rarely observed except for the government work or donor project including valley dam for paddy field.

Specific soil conservation measures are not widely practiced in the hillside farming, and gully erosion on feeder roads to downhill toward wetland or marshland are usually observed. Three methods for soil erosion control are adopted in Rwanda: Contour Bund, Trench Ditch, and
Terracing. Contour Bund method is to set up the bank along the contour line; some grasses such as Napier grass (*Pennisetum purpureum*) are planted on the backs. Trench Ditch method consists of setting up ditch (length: 10m, width: 40-50cm, depth: 30cm). These ditches are found in some places in Gasabo District mostly, in some sectors such as Ntarama, Juru and Nyamata. Although terracing is relatively effective at steep slope but costly, it is found in most of farmlands. Small-scale soil erosion controls such as check dam, fence with rock and trees crossing the trails are rarely found.

To increase crop production, emphasis must be placed on strengthening rainfed farming through soil and water conservation, water management techniques on hill land. In order to exploit the available water resources appropriately, water harvesting and efficient reuse of rain water is the only answer to achieve the sustainable agricultural production on the limited arable land of Rwanda. Rainfed land contributes about 65 percent of world production emphasizing its importance and dominant contribution to world food production. Rain fed farming in Rwanda is being carried out in more than 95 percent of cultivated land. The land available for cultivation is 52 percent of the total surface area posing land scarcity for agriculture and need to improve land productivity. Presently, less than 3 percent of the arable land is under irrigation and remaining is rain fed area giving low production due to poorly distributed rainfall. In eastern parts of Rwanda, rainfed farming is carried out only during rainy season on hill land and during dry season land is left fallow resulting in poor land productivity. Land productivity enhancements in rainfed agriculture can be achieved by integrating components of water management.

In-situ rain water harvesting (RWH) systems aim to minimize seasonal variation in water availability such as droughts and dry spells (Rockstrom *et al.*, 2002). Under erratic rainfall conditions in the semi-arid zone of sub-Saharan Africa, a major contribution to improving crop
production can be anticipated from improved and up-scaled SWC and RWH conservation practices. When farmers in semi-arid Africa are asked to list their problems, drought always ranks higher than land degradation or erosion (Stroosnijder and Van Rheenen, 2001; Beshah, 2003; Biamah, 2005; Hella and Siegers, 2006). Remarkably, little research has been done on what farmers exactly mean by ‘drought’, or on what land management practices could mitigate their drought problem. From the perspective of poverty reduction (MDG no. 1) and the conservation of natural resources in Africa (MDG no. 7), it is important to take into account farmer’s perception of the production-reducing obstacle ‘drought’ (Taylor et al, 1988). Farmers’ perception of drought refers to the Green Water Use Efficiency, i.e. the fraction of rain that is used for plant transpiration.

During the last decade, the Southern and Eastern Africa Rainwater Network (SEARNET) with support from the Regional Land Management Unit (RELMA), a SIDA funded unit based in Nairobi, Kenya has been promoting rainwater harvesting in Eastern and Southern Africa. SEARNET has nine member countries including Kenya, Uganda, Ethiopia, Tanzania, Rwanda in East Africa, and Botswana, Malawi, Zambia and Zimbabwe in Southern Africa. Between the years 2002 and 2006, a Global Water Partnership Associated Programme (GWP-AP) entitled “A Network for green water harvesting in Eastern and Southern Africa and South Asia” championed awareness creation, policy research, and capacity building activities on rainwater harvesting activities in 18 countries. By the end of the first phase of the programme in December 2006, the following problems were still outstanding in the ESA region:

- Poor access to and availability of water in the region due to inadequate water harvesting infrastructure - water storage falls below 1700 m³ capita ‘/year'(international minimum).
• Extremely low agricultural production - less than one tonne per hectare due to interseasonal dry spells and drought; this has been exacerbated by climate change and weather risk - these could be mitigated through supplementary irrigation and in-situ RWH and ground water recharge

• Poor management of rainwater - flooding, erosion, ecosystems, pollution

Research on in-situ water harvesting systems at region level could bring out necessary guidelines on how best rain water can be stored in soil profile with respect to crop season facilitating planning of water storage structures and application methods for supplemental irrigation.

Most national governments in Eastern and Southern Africa (ESA) only allocate money for conventional water supply systems such as boreholes and dams as a means of water for agricultural, industrial and domestic use. However, such systems are often centralized, expensive and benefit mainly those in urban areas. Although in-situ RWH has proved effective in both rural and urban settings, the governments have paid little or no attention to including this in their national economic development strategies and action plans. Thus, improving water management and governance are catalytic entry points for efforts to help developing countries fight poverty and hunger, manage and protect natural resources. To achieve overall agricultural sector goal of sustainable economic growth and social development within the framework of Rwanda vision 2020, Intensification and Development of Sustainable Production Systems Programme has been formulated. As part of this programme, a Memorandum of Understanding signed on 1 April 2007 between the Rwandan Government through Ministry of Agriculture and Animal Resources (MINAGRI) and the World Agroforestry Centre based in Nairobi, Kenya to facilitate implementation activities aimed at increasing water availability in the agriculture sector using simple decentralised, participatory, location specific rainwater harvesting technologies. This
study by providing information on variation of soil moisture pattern in the soil profile will help to plan rain water harvesting, supplemental irrigation particularly in Eastern parts of Rwanda.

In Rwanda, almost 90 percent of the potential soils for agricultural production are located in hillsides with very steep slopes (Delepierre and Prefol, 1973). Crop cultivation suffers with land productivity and poor yield due to insufficient rainfall during dry season especially in Eastern parts of Rwanda. Therefore supplementary irrigation and moisture conservation techniques must be adopted to fight against soil moisture deficits so that land productivity and yield can be increased. This project work focuses on performance evaluation of insitu soil moisture conservation techniques with respect to soil water storage during maize cultivation under low rain fed condition. At present, farmers are practicing widely ridges & furrows, plain field for maize cultivation on bench terraces. Compartmental bunds and vertical mulching are the other available options and the latter is not suitable for this area because of porous subsoil. Performance of these techniques to conserve soil moisture and the extent of supporting the crop under site specific environment is not well understood. This information provides basic input for selection of suitable conservation method and crop planning.

1.3.4 Insitu water conservation

In Rwanda, insufficient and erratic rains lead to significantly poor yields during the dry season. In the past water management research in Rwanda has focused on how to limit surface runoff but generally using potential of surface water for agriculture purposes are still insignificant (ISAR 2004).

Water is a major constraint for crop growth, due to the frequent occurrences of dry spells and drought in semi arid areas in Rwanda. Small holders’ farmers rely heavily on their lands for food security and household income. Failing rains have large implication of those household and
affect the ability to maintain adequate long term food supply itself and also to generate cash for other expenses and new investment. These constraints result in the apparent gap between small holder farmers’ productivity per hectare as compared to on station or commercial farmers yield levels; but contrary to the general belief, there is often enough rainfall to improve productivity. The problem is that too little of the rainfall is available to the crop at the right time (FAO, AQUA ST, 2004)

In crop production depending on the stage capacity available in the root zone, the first step in the management of the rainwater for plant growth is to capture it and enhance its infiltration in the soil profile. The next step of equal importance is to prevent or reduce water losses from the root zone. The third step is to implement cultural practices to ensure that the crop makes most effective use of the scarce water. The techniques for achieving these have been developed extensively under the subject of soil and water conservation.

In Rwanda, much attention has been taken on how to limit surface runoff and improve soil infiltration in the farmers’ field. Farmers to reduce soil from the field have used a wide range of technologies and intervention. Examples are mulching, terracing, hedgerows and pitting. These can be classified as in situ rainwater harvesting measures.

Although these in-situ water harvesting measures to improve soil moisture for crop as compared to no the interventions, farmers still experience severe crop water deficit and low yield in the country (1SAR, 2004).

1.3.5 Irrigation

Rwanda is one of the most densely populated countries in Africa. For 2004, the population is 8.5 million people on a surface area of 26,338 square kilometers; the land area is 24,948 square kilometers while water occupies about 1,390 square kilometers. In Rwanda, the
arable lands are estimated to be 1,380,000 hectares (52 percent of the total lands) for a physical
density of about 325 people per square kilometer. This excessively rapid expansion of the
country’s population concurrently with high rate of urbanization has brought about a special
problem on the provision of enough food to feed its people. In fact, the demographic pressure
leads to a rapid decline in size of farms and the cultivation on excessively steep slopes without
any erosion control measures. The agricultural production system in Rwanda is characterized by
small arable lands, with a familial exploitation of 0.8 hectares. Due to the decline of soils fertility
on hill slopes and overall climate change, swamps are the most important remaining land
resource for the development of agriculture in a country like Rwanda whose backbone is
agriculture. Therefore, irrigated agriculture will remain to be important for providing food and
livelihood security to the fast growing population (MINAGRI, 1999).

In the semiarid environment of Rubirizi, water allocations that result in crop water stress
can have a significant impact on corn growth, development, and yield. Knowing how much yield
can be expected from a given water allocation, however, is complicated by the fact that corn
yield is affected not only by the amount of seasonal irrigation, but also by irrigation timing. Also,
yield is affected by other sources of water available to the crop in addition to irrigation. These
sources include water stored in the soil profile at crop emergence and effective rainfall occurring
during the growing season. Many researchers have shown how corn grain yield can be affected
by irrigation timing (Jurgens et al, 1978; Jama and Ottman, 1993). Most of these studies show
that corn yield is most affected by water stress when it occurs during the reproductive stages
(tasselling, silking, pollination and grain filling). In Nebraska, the reproductive growth stages
coincide with the period of peak crop evapotranspiration (ETc) requirement, making stress
during these stages even more significant.
Expansion of irrigated areas and efficient water management will enhance the food supply in the coming decades (Yudelman, 1994). Proper management of inputs using modern technology, particularly irrigation water management, is essential to maximize crop production and returns for the farmers (Panda et al., 2004). The aim of irrigation is to optimize the yield by minimizing the damage caused by water stress during crop development (Stone et al., 2001a). Because water availability is limited and costs are increasing, there is an urgent need to save water and reduce water wastage while still maintaining adequate yields.

A well-managed irrigation envisages maximum yields per unit of water applied with a minimum of unavoidable losses while guaranteeing ecological sustainability. Drip irrigation is the most effective method in terms of maximizing yield and water conservation as well as providing efficient use of limited water. Rising irrigation costs, low commodity prices, inadequate irrigation systems and limited water supply are among the reasons that prompt many farmers to deliberately apply less water than is required to obtain maximum yield (Craciun and Craciun, 1999). Identifying growth stages of a particular cultivar under local climatic and soil conditions allows irrigation to be scheduled to maximize crop yield and to use efficiently scarce water resources (Doorenbos and Kassam, 1979). Karam et al. (2003) stated that water deficiency significantly reduces dry matter accumulation. Grain yield was reduced by 37 percent due to a decline of 18 percent in kernel weight and 10 percent in kernel number under water stress conditions. Yildirim et al. (1996) stated that the highest (10.85 tons ha\(^{-1}\)) and lowest (3.47 tons ha\(^{-1}\)) yields were obtained with full irrigation and without irrigation, respectively, during the total growing period in Turkey.
1.4 Statement of the problem

Rubirizi site located in the outskirts of Kigali city where rainfall occur in two seasons, a long rainy season and a low rainy season and the mean annual rainfall is approximately 1177 mm year⁻¹. Normally this amount of rainfall is not less even if some dry period occurs in bad years. The only problem is its distribution for crop rising as is the case in many eastern part of the country and on this amount of rainfall, too little of its quantity is available to the crop at the right time.

This is why the study on the performance evaluation of mechanical water conservation measure on terraced land was conducted in that areas in order to evaluate alternative techniques to cope with the problem stated above and improve land production. The capacity of water harvesting structures will be decided based on storage capacity of the soil column and its seasonal variation. This demands the need of understanding rain water intercept and its distribution and contribution to different components of water balancing process. Also study of impact of various soil properties will support us to determine the water conservation technique suitable to the area under study.

1.5 Justification

Terrestrial rain is the source of our global stock of fresh water, of which 65 percent is ‘green water’, i.e. rainfall that is stored in the soil and available to plants. Infiltrating water may be held in the soil - as green water (Ringersma et al., 2003) - or drain to groundwater and stream base flow. Runoff, stream base flow and groundwater may be dubbed blue water. Nearly all the world’s attention, research and development efforts have gone into blue water. Although irrigation plays an important role in food production, the possibilities of further extension seem to be limited, since water resources of sufficient quality become scarce or too expensive to use.
Since an increasing population requires increased food production, more efficient use of rain in rainfed agriculture deserves our increased (scientific) attention.

The study has been conducted at Rubirizi Terraced area known as ISAE Rubirizi farm. The area is well known for having low rainfall especially during May to August. In Rubirizi, rainfed farming is practised and rainfall is insufficient to support crop production consistently and land is left fallow. The problem is further aggravated by fast drying of soil by hot weather and poor water holding capacity of coarse textured laterite soil. Therefore, crop production is affected due to soil moisture stress during dry season. For improving soil moisture and crop productivity water conservation measures are required and it is impossible to store water without lining harvesting structures which is somehow expensive. So, suitable method of in situ soil moisture conservation has to be decided based on storage capacity of soil and its seasonal variation. If the soil is kept always to its maximum storage capacity by suitable water conservation measures during cropping period, expensive water harvesting structures may not be required. This needs to understand rain water interception, its distribution and contribution to different components of water balancing process. Also information on variation of soil moisture pattern in the soil profile will help us to plan rain water harvesting, supplemental irrigation and cropping pattern.

The study area to represents the hydro climatic conditions prevailing in eastern part of Rwanda which needs alternative techniques to cope with dry season and improve land productivity. In the area of study rain fed farming is being carried out for crop production. But adequacy of available rainfall and its distribution for crop rising are under question. In most areas of Rubirizi, Bugesera and in eastern parts of Rwanda land is left fallow because of
untimely and insufficient rain. The following study explores the best technical option to resolve the constraints in rain fed farming.

Data from this study will help to see how best rain fed farming can be supplemented by soil moisture conservation techniques and will show the appropriate type of agriculture to be practiced in the area of study.

The primary source of water for agricultural production for most of the world is rainfall. Three main characteristics of rainfall are its amount, frequency and intensity; these values vary from place to place, day to day, month to month and also year to year. Precise knowledge of these three main characteristics is essential for planning its full utilization applying suitable conservation measures. There is no simple way of classifying methods of water conservation. One suggestion is to do it by comparing rainfall with crop requirements (Narayana and Rambabu, 1985), giving three conditions:

1. Where precipitation is less than crop requirement here the strategy includes land treatment to increase run off onto cropped areas, fallowing for water conservation, and the use of drought-tolerant crops with suitable management practices.

2. Where precipitation is equal to crop requirement here the strategy is local conservation of precipitation, maximizing storage within the soil profile, and storage of excess run off for subsequent use.

3. Where precipitation is in excess of water requirement, in this case the strategies are to reduce rainfall erosion, to drain surplus run off and store it for subsequent use.

There can be wide variation of moisture storage and storage, both within and between seasons. A drought year whose total rain is well below the long-term average may still include periods of excessive rain and flooding, while a high rainfall season may include periods of drought.
This makes the choice of method difficult, because the desired objective may from the season to another. In a dry area it may be sensible to increase surface storage to increase the yield in most years. On the other hand a drainage system may have the objective of increasing the run off but also have the undesired effect of exaggerating the effect of a drought. It is therefore not practical either to classify methods according to average conditions, or to design strategies based on averages. The art of science of water management is to reduce the problems caused by non average event of flood and drought.

Sometimes it may be possible to have dual purpose methods which can be changed mid season, for example by opening up the ends of contour bunds to shed surplus water after a wet start to the season, or to block outlets for the opposite effect. But not many methods allow this flexibility. In this project the effect of different moisture conservation methods on soil water are evaluated using scientific principles.

1.6 Relevance of study

In Rwanda spatial and temporal distribution of rainfall results in soil erosion and moisture stress on agricultural crops; this remains an important cause of low crop production on one hand. On the other hand, ineffective and inefficient water harvesting and reuse usually leads to freshwater run-off. Another problem is low interest of farmers to use appropriate agricultural techniques aimed to increase crop production. Faced with above problems, the Government of Rwanda has set several measures to address food security, poverty reduction, maximization of crop production per unit area and to improve livelihood of the rural population. Crop production under smallholder irrigation schemes is seen as one of the means of implementing the Green Revolution (Postel S. 1999). Therefore, Rwanda is achieving remarkable progress in water
resources development through government led development projects by building dams/barrages and irrigation water systems in swamps.

However, saturation has come in developing the swamps for agriculture while hill land agriculture in Eastern parts of Rwanda is still at infant stage. Time has come to exploit and develop hill land for agriculture by providing appropriate pressure irrigation techniques. In Rwanda, almost 90 percent of the potential soils for agricultural production are located in hillsides with very steep slopes (Delepierre and Prefol, 1973). Crop cultivation suffers with land productivity and poor yield due to insufficient rainfall during dry season especially in Eastern parts of Rwanda. Therefore supplementary irrigation and moisture conservation techniques must be adopted to fight against soil moisture deficits so that land productivity and yield can be increased. In Rubirizi rainfed farming is practised and rainfall is insufficient to support crop production consistently and land is left fallow. The problem is further aggravated by fast drying of soil by hot weather and poor water holding capacity of coarse textured laterite soil. Therefore crop production is affected due to soil moisture stress during both crop seasons. High yielding long duration varieties of crop could not be adopted because of insufficient and erratic rain. This research focuses effect of different irrigation regimes on high yielding long duration maize variety cultivated on hill land to maximise yield through efficient supplemental irrigation techniques.

1.7 Objectives

In order to increase crop production and bring more area under cultivation on sustainable basis to cope with increasing food demand, the study had been conducted with a general objective of assessing the possibility for additional crop production during the long dry season, while regular crop production is carried out during wet seasons with low yielding short duration
varieties of crop. To explore the best technical option for resolving the constraints in rainfed farming on hill land, the following specific objectives were set.

1. How best rainfed farming can be supplemented by soil moisture conservation techniques?
2. How best maize crop utilises available soil water during different growing stage?
3. How far are the crop water needs met by rainfall?
4. What type of agriculture should be practiced in low rainfall hill land areas?

1.7.1 Main objective

The main objective of the study is to evaluate different in-situ water conservation techniques and supplemental irrigation regimes on maize crop in terraced land.

1.7.2 Specific objectives

In order to support efficient planning of water management for increasing the productivity the study of performance of terraced land under different water conservation techniques was done with the following objectives:

• To monitor soil moisture variation in soil profile.
• To study effect of water conservation techniques on soil moisture.
• To compare the interaction between water conservation structures and mulch
• To analyze available water and water deficit during cropping period.
• To study the effect of irrigation regimes under different doses of organic manure on maize crop
• To study the water use efficiency under different irrigation regimes.

1.8 Hypothesis

To feed the growing population in Rubirizi, more irrigation is needed to increase crop yield but the quantity of irrigation water is extremely limited. Therefore other sources of irrigation water like ground water, surface/subsurface water have to be sought for. As rainfall in the district is often lost through evaporation, infiltration and runoff, in-situ moisture conservation, supplemental
irrigation with ground water harvesting which might be other alternatives. The following hypotheses have been verified by this research.

1. Insitu water conservation techniques can improve the soil moisture content.
2. Yield of maize crop increases with irrigation water and the addition of organic matter.
3. Drip irrigation increases water use efficiency of maize crop
4. Drip irrigation is feasible for high yielding long duration maize cultivation