CHAPTER V
DISCUSSION

Preliminary studies were conducted to compare study of in-situ soil moisture conservation techniques in bench terraces and unterraced field with maize crop had been conducted. Based on the preliminary study results obtained in second seasons of 2007 and 2008, suitable land configuration, mulching and different irrigation regimes with drip irrigation was formulated and test verified during first seasons of 2008 and 2009. Moreover in another experiment drip irrigation with different lateral spacings and basin irrigation were compared under different irrigation regimes and organic manure doses. The results obtained are discussed in this chapter, under the following headings.

5.1 Preliminary studies on land configuration versus soil moisture on maize in 2007
5.2 Studies on land configuration and mulching on maize in second season in 2008
5.3 Effect of land configuration, mulching and supplemental irrigation
5.4 Effect of irrigation regimes and organic manure application
5.5 Cost analysis

5.1 Preliminary studies on land configuration versus soil moisture on maize in 2007

Occurrence of timely rainfall in sufficient quantity is the prime requirement for successful rain fed agriculture. Insufficient rainfall during dry season attracts the need of in-situ soil moisture conservation water harvesting and supplemental irrigation. The study has been conducted in ISAE terraced farm at Rubirizi with the objective of evaluating in-situ soil moisture conservation techniques for having an additional maize crop yield by crop planning and water management.

The study explores the best technical option to resolve the constraints related to water management in rain fed farming. Comparative study of in-situ soil moisture conservation
techniques in terraces and unterraced field with maize crop had been conducted from June 2007 to October 2007. Analysis of rainfall and crop water demand indicates that it is inevitable to provide supplemental irrigation and in-situ moisture conservation for successful crop in this region. Bench terrace increased the average soil moisture content in 90cm soil depth by more than 50 percent than that of unterraced land. Within the bench terraced field compartment bund increased average soil moisture by 19.5 percent higher than plain bed with a coefficient of variation of 20.4 percent and ridges & furrows increased by 27.9 percent with coefficient of variation of 28.6 percent. This indicates that in-situ moisture conservation measures are effective to increase soil moisture compared to plain bed. It is also found that mean soil moisture fluctuation in the soil profile is moderately more at 60cm depth compared to 30cm irrespective of type of conservation technique.

Performance of ridges & furrows, compartmental bund and plain land was evaluated in terms of soil moisture conservation. The study reveals that Compartment bund performed well in both 30cm and 60cm soil depths followed by ridges & furrows because of consistent soil moisture as evidenced by less coefficient of variation. Higher moisture content in these two techniques is due to water barrier to harvest rainwater. Average soil moisture content for compartment bund and ridges & furrows varied between 16 to 17 percent and 13 to 14 percent for plain bed at both 30 and 60cm soil depths.

In all the three techniques, actual soil water during the entire study period remained below field capacity posing soil moisture stress. No maize yield was recorded in all the techniques because the soil water depleted to 60 percent and above from the beginning of the study period inferring the need of supplementary irrigation. Plain bed exhibited lowest degree of fluctuation of deficit water indicating poorly influenced by rain fall as compared to ridges &
furrows and compartmental bund. In terms of efficiency of moisture conservation during the study period, ridges & furrows performed well with 85.8 percent followed by compartment bund with 75.9 percent in terraced field. Un terraced field conserved moisture very poorly with 13.9 percent efficiency inferring importance of bench terraces for soil moisture conservation.

Shaxson et al. (1989) and Hudson (1992) advocated aiming at land husbandry rather than at soil and water conservation, the difference being that land husbandry involves an integrated set of land management practices intended to increase or maintain land productivity. What semi-arid Africa needs is a regreening of the landscape (Stroosnijder, 1992). Not a narrow focus on ‘more crop per drop’ but rather a focus on ‘more biomass per drop’. Planting trees, shrubs provide good run off reduction and soil water storage particularly in hill lands, thus reducing soil degradation. Soil degradation and soil water storage are interrelated.

A general problem in semi-arid areas is the lack of soil organic amendments, including mulch (Aklilu et al., 2007). However, water conservation and water harvesting result in a greater share of the rainfall for green biomass. By enhancing GWUE, water conservation practices will not only provide more available water for food crops but also for grasses, shrubs and trees, part of which can be used as mulch. Mulching will create a win-win situation, because the mulch will not only reduce E but also contribute to the maintenance of soil organic matter, thus enhancing the physical quality of soils. Mulching is one of the three key elements of land husbandry (Hudson, 1992) also known as conservation agriculture.

Development of dry land or rainfed areas, does not mean that no irrigation development at all takes place as part of the programme. Giving one or two light irrigations to a crop at certain critical stages of water stress during its growth cycle is now recommended in dry farming. Evidently dryland agriculture needs to be given the most attention in regions where there is little
scope for additional development of irrigation sources. In India, Danida helped to improve dry land through soil and water conservation and water harvesting measures, including providing a borewell for every 10 ha of land cultivated. There is tremendous potential for improving production in rainfed agriculture through supplemental irrigation by micro irrigation systems using conjunctive use of ground water and runoff water harvesting. It is suggested to adopt lift irrigation for hill land agriculture. This needs further studies on ground water exploration to ensure its availability. Detailed analysis is needed for feasibility of lift irrigation with different crops under different altitudes to derive suitable policy for hill land irrigation. Feasible zones of altitudes for different crops should be demarcated on hill land based on its economical viability.

This research suggests that a promising avenue of upgrading rainfed agriculture is through water harvesting and supplemental irrigation that enables mitigation of dry spells. Such measures involve adding a blue water component, through tapping of surface runoff and ground water, to the rainfed system, i.e., developing rainfed farming into a more blended blue-green system by adding a small irrigation component. Carried out at large scale may have implications on downstream blue water availability. However, it is not certain that an increase in return flow of evapotranspiration in rainfed agriculture upstream automatically results in reduced water availability downstream. Finally it is argued that some of the most exciting opportunities for water productivity enhancements in rainfed agriculture are found in the domain of integrating components of irrigation management within the context of rainfed farming, e.g., supplemental or micro irrigation and conjunctive use of ground water for dry spell mitigation. The most suitable technology available for rainfall management for rainfed farming is determined through a rational analysis of rainfall, identification of the critical irrigation periods of the crops grown, estimation and collection of excess runoff into designed tanks after taking into account effect of
soil and water conservation measures and in situ moisture conservation, and adopting a suitable 
irrigation system.

5.1.1 Soil water dynamics (Fig 42 to 44 and Table 65)

Data collected on rainfall, pan evaporation, soil moisture and field capacity in the 
experimental fields during the observation periods are used to analyze water balance components 
in 90 cm. soil depth which is the effective root zone of maize crop. Compartment bund, ridges & 
furrows and the poorest performing plain land are considered for water balance analysis. Actual 
soil water and water deficit in. the soil are the parameters analyzed. Water deficit has high 
coefficient of variation of 42 percent in ridges & furrows followed by 28 percent in compartment 
bund indicating the degree of influence by rain water.

![Fig 42 Variation of soil water compared to field capacity in Ridges & Furrows](image)

In all techniques the actual soil water during the entire study period remains below field 
capacity posing soil moisture stress. In ridges & furrows and compartment bund the actual soil 
water is somehow approaching the field capacity at the end of the cropping period due to onset 
of rain. The primary factor controlling dry land com grain yield in the semi-arid region, is
available water from stored soil water and growing season precipitation (Campbell et al., 2005), Lyon et al. (2003) concluded from their simulation studies, that dryland maize should not be planted when available soil water at planting was less than 80 mm. The data from this study showed clearly that there is always a positive response of corn grain yield to increasing available soil water at planting under dryland conditions, confirming the recommendation that every effort should be employed to increase precipitation storage efficiency during non-crop periods through good residue management and weed control.

Fig 43 Variation of soil water compared to field capacity in compartment bund

Flat bed exhibits low degree of fluctuation of water deficit indicating poorly influenced by rain water as compared to other techniques. During period of mid stage which is more crucial for maize crop in the study period, soil water was below wilting point in this treatment. Li et al. (2000b, 2001) recommended the RF micro water harvesting system to improve water availability and increase crop production under semi-arid conditions in Northwest China. Wang et al. (1999a, b) showed that crops with long growing periods and great potential productions were
high-yield raising and produced more income under RF system. The RF system can collect water, aid water permeation, improve the root system’s moisture level and hence remarkably elevate crop production in semi-arid and drought-inclined areas (Hu et al. 1997). The result showed that mulching ridges with narrow furrows is better than mulching ridges with wide furrows. Therefore choosing optimum ridge: furrow ratios and suitable ridge-covering materials are of great importance to the development of a more effective RF system.

Table 65 Statistical parameters of soil water and water deficit

<table>
<thead>
<tr>
<th>Statistical parameters</th>
<th>Plain bed</th>
<th>Compartment bund</th>
<th>Ridges &amp; furrows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual soil water cm</td>
<td>Water deficit cm</td>
<td>Actual soil water cm</td>
</tr>
<tr>
<td>Average, cm</td>
<td>14.91</td>
<td>16.99</td>
<td>17.8</td>
</tr>
<tr>
<td>Standard deviation, cm</td>
<td>4.0</td>
<td>4.0</td>
<td>3.63</td>
</tr>
<tr>
<td>Coefficient of variation percent</td>
<td>26.78</td>
<td>23.51</td>
<td>20.37</td>
</tr>
</tbody>
</table>

According to Xiao et al. (2006), soil moisture storage is higher for the plastic-covered ridge and furrow methods of rainwater harvesting treatments than the trench, bare ridge and bare furrow particularly for soil moisture at soil depth of 100-200 cm, suggesting that more water was recharged into the deeper soil layer by the plastic-covered ridge treatments. This is due to the fact that plastic-covered ridge has a low rainfall threshold for generating runoff, and more water can be harvested. Li et al. (2000) reported plastic-covered ridge could generate runoff at a threshold value of 0.8 mm rainfall and RF treatments had 11-114 mm more water than the
controls at soil depth of 0-100 cm, and 24-55 mm at soil depth of .100- 200 cm. This is inline with the present study inferring higher soil moisture at deeper soil depth than, the top soil.

![Graph](image)

**Fig 44** Variation of soil water compared to field capacity in flat bed

### 5.1.2 Soil water depletion percent and available soil water (Fig 45 to 47)

Variation of depletion percent among the conservation techniques and flat bed shows more soil water depletion because of poor rain water harvest compared to other treatments.

Soil moisture content in 90 cm soil depth at field capacity and wilting point are taken as 31.9 cm and 10.8 cm respectively. Maximum available water in root zone depth of 0.9 m is 21 cm. Unterraced land exhibited highest available soil water depletion percent of more than 110 percent throughout the cropping season, implying soil moisture below wilting point. In terraced land, Plain bed (control) reached 100 percent depletion of available water particularly during vegetative and early mid stages whereas compartment bund and ridges & furrows remained with more than 70 percent depletion. This clearly demands supplemental irrigation particularly during
periods falling in initial and mid crop stages in terraced land whereas unterraeetfiand needs irrigation throughout crop duration.

![Variation of soil water depletion percent between treatments](image)

**Fig 45** Variation of soil water depletion percent between treatments

Variation of soil available water was observed under all the conservation techniques and it is compared against crop water demand. Compartment bund and Ridges & furrows followed by the plain land have available water more than the crop water demand during flowering to harvest stage. Vegetative stage of the crop suffered with soil moisture stress in all the techniques resulting failure of yield. Flowering was observed when available soil water was more than crop water demand posing no soil water stress. But no maize yield was recorded in all the techniques because the soil water depleted to 60 percent and above from the beginning of the cropping period.
Fig 46 Available soil water and crop water demand

For the best recommended moisture conservation technique of compartment bund, depletion percent of available soil moisture during different growth stages of maize crop varies from 60 to 85 percent during development and mid stages which demands supplemental irrigation.

Fig 47 Depletion percent at different growth stages of maize in compartment bund

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The maximum amount of stored water in the root zone available for plant growth (i.e. plant roots can extract the water from the soil) is a very important soil characteristic because it determines the survivability of plants in a dry spell (i.e. periods of consecutive days without effective rain). This Total Available Water (TAW in mm) in the rootable part of the soil profile can be approximated as (Stroosnijder, 1982):

\[ TAW = RD \times Q_0 \times FC - WP \]

In which RD is the rootable depth (mm), FC the field capacity, WP the wilting point, i.e. the moisture content if the water potential equals -1.6 MPa and 0.9 accounts for 90 percent depletion percent. When plants are in soil at WP they will die, hence the depletion of 50 percent is considered keeping poor water retention capacity of soil. In a non-degraded soil with average physical properties the effective rootable depth of maize can be 900 mm and \((FC - WP) = 31.9 - 10.8 = 21.1\) cm Hence, \(TAW = 105\) mm. With an actual evapotranspiration of 5mm/day, the stock of water in the root zone of maize crop is sufficient for a dry spell of 21 days.

Of course, this only holds if the soil moisture was at field capacity at the start of the dry spell. But in our case it remained 30 percent below field capacity indicating that the soil moisture will be sufficient for less than 21 days in case of 900 mm rootable depth. In hill land soil with porous rocky substratum, the rootable depth is often reduced because of terrace formation. Furthermore, the soil texture will have become coarser due to selective removal of the finer particles and the structure will have degraded due to the decrease of soil organic matter. This leads to effective rootable depth of only 400 mm and an \((FC - WP)\) of only 94 mm. This implies that TAW is only 47 mm and sufficient for only 9 days. This change in the length of the dry spell that plants can endure is what farmers mean by their ‘drought’ problem. Variation of available soil water depends on effective rootable depth which in turn depends on soil depth in that area. In the experimental area, in middle portion of the terrace has effective rootable depth of only
400mm whereas in the bottom of the hill it is 900 mm. For this reason crop cultivation suffers in middle portion of the hill compared to bottom of the hill. Even if supplemental irrigation is given less water with more frequency shall be followed whereas in the bottom of the hill more water with less frequency of irrigation shall be followed.

5.1.3 Water harvesting and Supplemental irrigation

In dry land areas, irrigation intervention is believed to improve the productive potential from very low to better. Yield increases by 100 to 400 percent have been recorded in developing countries through irrigation (FAO, 1997). Irrigation also reduces the risk of crop failure and can lead to multiple cropping. Barron (2004) investigated the possibilities for water harvesting and supplemental irrigation (SI) in Kenya. Dry spell analyses showed that potentially yield-limiting dry spells occur at least 75 percent of seasons for two locations in semi-arid East Africa during a 20 year period. An on-farm experiment was conducted during 1998-2001 in Machakos district, semi-arid Kenya. Surface runoff was collected and stored in a 300 m$^3$ earth dam, from which gravity-fed supplemental irrigation (SI) was applied to a maize field down slope. Combinations of no irrigation (NI), SI and three levels of N fertilizers (0, 30, 80 kg N ha.) were applied. Over 5 seasons with rainfall ranging from 200 to 550 mm, the crop with SI and low nitrogen fertilizer gave 400 percent higher yields than the farmers’ conventional in-situ water harvesting system. Adding only SI or only low nitrogen did not result in significantly different yields. However, its adoption by farmers will depend on other factors, including investment capacity and know-how. So, for Rwandan conditions adoption of irrigation without land management practices will result in non productive investment. Pimentel (2006) clearly indicated that the lower water availability due to land degradation and soil erosion to be a major global threat to food and the environment.
There is a need to enhance protection against soil and water losses through terracing and insitu water conservation measures.

In the study area, it is observed that bench terraces increased rainfall infiltration, porous substrata facilitated percolation of infiltrated water resulting good recharge of ground water in the swamp. Since the swamp is surrounded by terraced hill on both sides plenty of ground water is accumulated during rainy season and available for dry season. This valuable ground water source is not exploited and remains unutilized. The situation is more common in Rwanda which is commonly called as country of thousand hills. There is tremendous potential for improving production in rainfed agriculture through supplemental irrigation by micro irrigation systems and low nitrogen fertilizer as evidenced in Kenya. It is suggested to construct shallow well for tapping ground water and adopt lift irrigation to support hill land agriculture. This needs further studies on ground water exploration to ensure its availability. Annual rainfall of 1177 mm, occurrence of spring water and shallow ground water depth of less than 1.5 m during dry season in the swamp are evidences for availability of ground water. Elevation difference of more than 50 m between the swamp and hill in most of the cases in Rwanda questions feasibility of lift irrigation. Detailed analysis is needed for feasibility of lift irrigation with different crops under different altitudes to derive suitable policy for hill land irrigation and cropping pattern. Feasible zones of altitudes for different crops should be demarcated on hill land based on its economical viability. It is recommended to go for commercial crops in higher elevations of hill to make the irrigation system feasible. Beyond the feasible altitude, runoff harvesting in farm ponds using micro catchment should be practiced for supplemental irrigation. The viability of increasing the implementation of water harvesting in a catchment needs to be assessed so that other downstream users of water are not compromised.
For dry land agriculture water harvesting denotes collection of excess runoff in a storage tank and using it for the betterment of crop production in the collected or other areas. There are three types of collector tanks, namely farm ponds, percolation ponds and silt detention tanks. The water collected in the farm pond is directly used for protective irrigation. The water stored in other structures will recharge the groundwater and is used for protective or supplementary irrigation by digging wells. According to Verma et al (1989), a study conducted in Punjab, India, had shown that 54 percent of the catchment area can be irrigated once with 5 cm depth of water so collected. Further, it was observed that the average response of one such supplementary irrigation to maize at its most critical stage increased the grain yield by 0.4 t ha\(^{-1}\) in the case of maize. In the case of maize tanks designed on a periodical runoff basis, the benefit-cost ratio varied from 1.6 to 4.56. This ratio increases with the capacity of the tank. Considering average farm size of 0.12 ha, with 300 m\(^3\) capacity lined storage tank, 2 cm supplemental irrigation is possible in vegetative and flowering stage with the pattern of rainfall during the crop season. For this 25 percent of terraced or unterraced area needs to be allotted for microcatchment. The most suitable technology for rainfall management in rainfed farming is determined through a rational analysis of rainfall, identification of the critical irrigation periods of the crops grown, estimation and collection of excess runoff into designed tanks after taking into account soil and water conservation measures including in situ moisture conservation, and adopting a suitable irrigation system. The required catchment area and tank size can be reduced if conjunctive use of ground water is adopted.

5.1.4 Land configuration

Raised bed planting practices have been developed in several areas of the world and over the past 15 years, studies have been conducted on permanent raised bed planting systems under high
input, irrigated situations in arid conditions of North Mexico (Limon-Ortega and Sayre, 2002; Limon-Ortega et al, 2000, 2006) and in rainfed situations in the central highlands (Govaerts et al, 2007). The permanent raised bed and furrow system, as one of the conservation agriculture technologies, reduces production costs while conserving resources and sustaining the environment (Sayre, 2004). Permanent bed planting is efficient in reducing soil loss as the furrows are checkers of the excessive runoff (Sayre, 1998). Reduced tillage systems offer advantages over conventional tillage through reduction in costs and by conserving soil and water (Deen and Kataki, 2003; Sisti et al, 2004). Besides, as the soil physical condition in the permanent raised beds is not disturbed by frequent tillage this could enhance the water infiltration rate and thereby reduce the proportion of runoff generated in each rainfall event; this can especially become important after some years of application of permanent raised beds combined with soil surface mulching (Govaerts et al, 2007). In our experiment, functions of raised bed in terms of reduced tillage and runoff are comparable to compartmental bund provided on terraces. Unlike ridges and furrows, soil is not disturbed in compartmental bund. Moreover the bunds are more capability in trapping runoff more consistently than ridges and furrows. This is evidenced by less coefficient of variation of soil moisture compared to ridges & furrows and plain land. Compared to ridges and furrows, compartmental bund results less production cost because of fewer earthworks.

Tewodros Gebreegziabher et al. (2009) studied Contour furrows for in situ soil and water conservation in wheat, Tigray, Northern Ethiopia. They reported that the trend of runoff in the terwah ploughing consisting of traditional ploughing followed by making every 1.5-2 m contour furrows indicates that in the beginning of the rainy season the terwah system is as efficient as the permanent raised beds with contour furrows at 60-70 cm interval in reducing the runoff volume
generated and thereby the runoff coefficient of the plots. However, with increased frequency and amount of rainfall later in the season, the runoff from terwah plot increased to an amount similar to that of the traditional ploughing. This is attributed to the smaller capacity of the furrows made at wider interval (1.5 m), which were filled by sediment transported from the broad beds, compared the smaller permanent raised beds. Hence the runoff traps when filled with sediment after some time contributed little to reduce the runoff for the rainfall events. Also the runoff coefficient increased with time for all treatments. The average runoff coefficient was reduced by more than 60 percent and 30 percent due to the permanent raised beds and the terwah system, respectively as compared to the traditional ploughing. Based on these facts, compartmental bund which has more volume of runoff trap per unit area than ridges and furrows is considered to be less vulnerable to runoff inducement due to damage of bund during the entire crop period. This was observed in the experimental plots of compartmental bund. In simple words, life of compartmental bund matches the crop period and serves more consistently.

5.2 Studies on land configuration and mulching on maize in second season (2008)

Performance evaluation of different in-situ water conservation techniques in terraced land in ISAE Rubirizi farm has been conducted from May to August 2008. The study is based on moisture content analysis performed by monitoring soil moisture measurement. Four techniques of moisture conservation with mulch were selected for the experiment and soil moisture data were analyzed in different periods.

The study shows that maize straw mulch performed well more or less in all structures particularly in ridges and furrows with maximum mean soil moisture of 12.5 percent and is followed by glass mulch. This is due to the thickness of maize straw mulch and resistance to air flow on soil surface provided by ridges. Grass mulching was done with fresh grasses which was
not dry like maize straw and lost weight after drying. So, quantity of grass straw has been increased if it is wet so that it will be comparable to dry maize straw.

The mean soil moisture content among the four types of water conservation techniques did not vary significantly at 15cm soil depth. The soil moisture content at 40cm depth is higher than that of 15cm but still the difference is very marginal due to the coarse lateritic soil and low organic matter content. Among the moisture conservation techniques, the analysis shows that compartment bunds and ridge and furrows can conserve more moisture than flat beds and broad bed furrows provided when there is rain.

Analysis of variance was performed by AGRES for the interaction of moisture conservation techniques and mulching. The analysis shows that maize straw mulched plots in flat bed followed by ridge and furrows and compartmental bund and grass mulched plot in compartmental bund has the best treatments in 15cm soil depth.

Considering the performance of different in-situ water conservation techniques in terraced land, it can be concluded that the combination of water conservation techniques with mulch perform well in terms of soil moisture conservation when there is moderate rainfall during the cropping period. In the present study, there is no rainfall in the second half of cropping period. Under such conditions, flat bed and compartment bund combined with maize straw mulch performed well in 40 cm soil depth in retaining soil moisture.

5.2.1 Effect of supplemental irrigation

As a preliminary study focussed on effect of supplemental irrigation on maize crop, the experimental plots with maize straw mulch were given varied supplemental irrigation from flowering stage onwards. Crop water demand, rainfall, soil water deficit during crop period and
their impact on maize crop performance under different supplemental irrigation regimes were analysed.

The total rainfall during crop period was 132.3mm against total crop water demand of 405mm. Irrigation was administered according to erratic rainfall. From germination to flowering stage life saving irrigation was given to all the plots with same quantity of water. From germination to 12th July a total of 207.6mm of irrigation was applied manually in all the three irrigation treatments.

In the first irrigation regime (I1), a total of 361mm water and in second regime (I2), 318.7 mm of water was applied. Flowering was observed June 29th and supplemental irrigation was started on 14th July. The difference in supplemental irrigation was given from 14th July and it has shown significant influence on crop yield. Supplemental irrigation of 160litres day⁻¹/plot⁻¹ was applied in three plots under regime I1; 240 litres day⁻¹/plot⁻¹ was applied once in two days plot⁻¹ under regime I2 and other three plots without irrigation under treatment I3.

Plots with no supplemental irrigation after flowering yielded no grains whereas plots which received irrigation yielded grains at the average rate of 1.8Tons Ha⁻¹ under regime I1 and 1.46Tons Ha⁻¹ under regime I2. Loss of crop yield due to soil moisture stress during flowering stage supports research findings of Musick and Dusek (1980) who reported that stress during tasseling and silking was the most harmful and stress during grain filling was more harmful than stress during vegetative growth.

Available soil water in root zone depth of 60cm was very critical in flowering stage since crop water demand exceeded available soil water posing soil water stress. This is evidenced by high depletion of available soil water about 60 to 90 per cent during flowering stage. There is more scope for getting higher yield by reducing soil moisture stress bringing depletion less than
50 percent. Maximum of 567mm supplemental irrigation water applied during crop period against the actual irrigation demand of 273mm under treatment II. This indicates poor soil moisture retention due to poor soil organic matter and low water application efficiency due to manual irrigation. This suggests use of increasing soil organic matter and adoption of modern irrigation systems like drip and sprinklers under water scarced conditions.

5.3 Effect of land configuration, mulching and Supplemental irrigation

5.3.1 Seasonal condition (Fig 48 & 49)

In the first crop season, rainfall received was 23.7 per cent lesser than normal rainfall whereas in the second year it was 26.6 per cent higher. Compared to the first year, second year received 27 per cent more rainfall and this resulted good plant growth and higher yield in the second year. High rainfall of 1047mm in year 2007 resulted in good ground water availability in the swamp and so better well yield was observed in 2008 compared to 2009.

![Graph showing Monthly rainfall for 2008 and 2009](image)

**Fig 48 Monthly rainfall**
Effective rainfall was 323mm in the first year while in the second year it was 409mm. Actual crop water demand was higher in the first year and in both the years effective rainfall was less than the crop water demand inferring the need of supplemental irrigation. In the first year crop water supply by rainfall and crop demand during vegetative and flowering stages was more compared to the second year. Flowering and maturity stages experienced good rain fall in the second year which is the main cause of higher production.

![Crop stage wise rainfall and crop water demand](image)

Fig 49 Crop stage wise rainfall and crop water demand

5.3.2 Growth components (Fig 52a to 52c and 53a &b)

In the present study, the growth components were influenced by rainfall and supplemental irrigation. In the first year, growth characters like plant height, LAI, stem girth and dry matter accumulation were depended on quantity of rainfall and supplemental irrigation received particularly in flowering and maturity stages. Insitu moisture conservation measures like BBF, CB played significant role to enhance the growth parameters. The maximum amount of water applied to the crop was 613mm including rainfall and supplemental irrigation, while the
minimum amount was 386 mm during the first year of the study. Less supplemental irrigation was given in the second year due to water scarcity in the shallow well. In the second year, the values were 515 and 446 mm, respectively. Amounts of irrigation water applied to the corn were reported as 533 786 mm in Texas (Yazar et al., 1999), 488 497 mm in the Aegean region of western Turkey (Dagdelen et al., 2006), and 300-730 mm in Niger, Africa (Pandey et al., 2000a), depending on the irrigation regimes used. The amount of irrigation water applied to the crop can change according to climatic and soil conditions. Even though the amount of water applied was lower in the second year, good production was achieved due to good rainfall in flowering and grain fill stages.

Seasonal water consumption (ETa) was 386 mm in the first year and 331 mm in the second year. Seasonal water consumption of corn was reported to be 474-605 mm in the Cukurova region of Turkey (Kanber et al., 1990), 353-586 mm in the Thrace region of Turkey (Istanbulluoglu et al., 2002), 505-568 mm in Spain (Cavero et al., 2000) and 920-945 mm in the Bekaa Valley of Lebanon (Karam et al., 2003). In the present study, seasonal water consumption values are lower for corn than most of the reported values due to the lower temperature and evaporation in eastern province of Rwanda during the first crop season. In North province of Rwanda, due to high altitude seasonal water consumption is still lower and most maize crop takes longer duration to yield. LAI values ranged from 1.18 to 1.96 at 75 DAP in the first year and from 2.08 to 2.66 in the second year. At 110 DAP, LAI ranged from 4.56 to 7.96 in the first year and 3.7 to 5.8 in the second year. Limited irrigation in the second year has resulted in less LAI, but due to good rainfall during flowering and grain filling stages, produced higher yield. Maximum LAI values were obtained for plants at good irrigation, and these values decreased with increasing water deficiency in both years. Tollenaar (1986) found that LAI values generally
ranges from 2 to 6 in maize. Other studies indicated that a water shortage during the growing period reduces the leaf area (Acevedo et al., 1971; Jamieson et al., 1995; Stone et al., 2001a). Pandey et al. (2000b) reported that the highest corn LAI was obtained under well-irrigated conditions. Muchow et al. (1986) stated that reduced leaf expansion rate leads to reduced biomass accumulation. Water stress during growth is also crucial to leaf area development, potential kernel number and subsequent yield.

The reduction of leaf area index was marginal from between land configurations and mulches due to marginal effect of variation in soil moisture stress during vegetative stage. However, a little more reduction in the leaf area index was noticed when irrigation water quantity was varied, affecting the root water extraction due to greater soil water stress. This trend was observed during both the years. The temporal variation of leaf area index (LAI) for different treatments during (2008-2009) infers that the LAI increased during the growth period of the crop till the end of silking and grain filling stage after which there was a slight decrease in the values. Irrigation regime] having minimum soil water stress gave the highest value of LAI at all stages of growth as per expectation. LAI in the second year was higher than the first year at 45, 75DAP but at 110 DAP, LAI it was less than the first year. This infers that vegetative growth continued even in flowering stage and resulted in reduction of grain yield in the first year. During vegetative growth sufficient water should be available to complete vegetation growth otherwise it may prolong if water is available at later stages.

In general, difference in plant height and stem perimeter between the first and second year was marginal due to total rainfall that occurred during the critical stages of maize in the second year was more than that in the first year. Good crop growth rate was observed in BBF followed by compartment bund under maize straw mulch in the second year. In the first year BBF
followed by ridges and furrows under maize straw mulch resulted higher crop growth rate at 30 to 60 DAS. Similar trend was observed in 60 to 110DAS. At 30 to 60 DAS, almost similar crop growth rate was observed in both the years but at 60 to 110DAS, second year recorded higher crop growth rate due to better soil moisture availability made by good rain fall.

5.3.3 Yield (51a to 51e)

Decline in grain yield was more prominent beyond the depletion level of 50 percent that is for the irrigation regime 1. This could be due to the fact that the soil moisture depletion level greater than 50 percent was sufficient enough to limit extraction of water by the roots and thereby affecting grain formation. Similar trends were observed during the other irrigation regimes. Maximum deficit of 78 percent observed in BBF under maize straw mulch with irrigation regime 1 in the first year whereas in the second year it was 70 percent during maturity stage. If this situation is improved by providing adequate supplemental irrigation there is a possibility to increase the grain yield.

Total rainfall that occurred during the critical stages of the maize crops such as: silking and grain filling in the years 2008 and 2009 were 117 and 156 mm, respectively. During the critical stages of growth, a minimum soil water stress of 70 percent depletion of available soil water was maintained since maintaining the field capacity level or 30 percent depletion with less water stress was not practically possible in the field. As rainfall during the critical stages in the first year was less than that in the second year; the grain yield was more in the second year than that in the first year. The crop experienced more stress during the critical stages of the first year due to failure of timely occurrence of rainfall when compared to the second year.

The lowest biomass yield in the first year under non irrigated conditions may be partly due to the high temperature and low relative humidity in the initial crop stages. Other factors, such as
low ground cover percent and LAI in the early growing stages, accelerate water evaporation from the soil. Kirtok (1998) found that water deficiency together with hot and dry climate during the growing period results in substantial yield reduction. Corn is relatively tolerant to water stress in the vegetative stage, very sensitive during the tasselling, silking, and pollination periods, and moderately sensitive during the grain-filling stage (Fischer and Palmer, 1984; Shanahan and Nielsen, 1987).

According to Tan et al. (1996), unfavourable climatic conditions and a poor water management regime could cause reduction in yield. Low humidity and high air temperature cause the stomata to close, resulting in less assimilation due to a decreased CO2 uptake for photosynthesis. Plants transpire more when the vapour pressure deficit of the air is high. The yield reduction observed when deficit irrigation was applied can be explained by the presence of water stress throughout the growing season and the correlation between yield and climatic conditions.

Irrigation application at critical growth stages is one of the important factors to improve the efficiency of crop water use and to achieve optimal crop production. Denmead and Shaw (1960) in Iowa reported that stress at silking reduced yield by 50 percent, whereas stress during the vegetative stage and after silking reduced yield by 25 percent and 21 percent, respectively. When no supplemental irrigation is given yield reduction compared to irrigation regime 1 ranged from 32 to 63 percent in the first year and 35.8 to 57.9 percent in the second year under different land configurations and mulches. BBF and compartment bund under maize straw mulch supported for good grain yield with supplemental irrigation regime 1 in both the years. When 50 per cent irrigation water is reduced, maximum yield reduction of 24.4 percent in the first year and 30.6
per cent in the second year was observed. This variation is due to the rainfall and other climatic parameters which supported for good soil moisture and ultimately better yield in the second year.

Therefore, it is assumed that ETc based irrigation is one of the efficient water delivery schemes, resulting in greater WUE and grain yield with less water input. While irrigation application at critical growth stages is one of the important factors to improve the efficiency of crop water use and to achieve optimal crop production, the irrigation management applied in this study was practiced based on actual crop water requirement.

The rates of irrigation water use efficiency ranged from 0.96 to 1.91 kg m\(^{-3}\) in the first year and 3.9 to 5.9 kg m\(^{-3}\) in the second year under irrigation regime 1. For irrigation regime 2, the values are 1.85 to 3.14 kg m\(^{-3}\) in the first year and 1.4 to 7.4 kg m\(^{-3}\) in the second year. WUE and IWUE values were different depending on the treatments and years. The highest WUE and IWUE values were obtained when irrigation water was applied 50 percent than that of irrigation regime 1 under drip irrigation with laterals spaced at 120cm. BBF and compartmental bund with maize straw mulch favoured highest irrigation water use efficiency in both the years of study.

IWUE values of 1.25–1.46 kg m\(^{-3}\) (Musick and Dusek, 1980), 1.38–1.80 kg m\(^{-3}\) (Koksal, 1995) and 1.02–2.43 kg m\(^{-3}\) (Gencoglan, 1996) have been reported. WUE values of 0.22–1.25 kg m\(^{-3}\) (Gencoglan, 1996) and 0.87–3.19 kg m\(^{-3}\) (Koksal and Kanber, 1998) have been obtained for corn. The findings obtained in this study are in agreement with those reported in the literature. The IWUE values of both years were higher than the WUE values. Because there was good rainfall during the growing season, the differences between the two values could be attributed to the supplemental irrigation water and soil moisture retained by land configurations and mulching used. Karam et al. (2003) reported that stressed plants have higher WUE values than well-watered plants. This increase in efficiency is due to a larger decline in plant transpiration because
of reduced green leaf area as a consequence of water stress, which has probably also reduced the evaporation from the dry soil. Water management through controlling the quantity of irrigation water during vegetative growth and/or reproductive growth deserves attention in high evaporative environments to minimize the reduction of crop growth and yield and achieve higher efficiency in water use (Eck, 1985).

5.3.4 Soil moisture (Fig 50)

Significant difference in water storage in the soil profile (0-90 cm) was recorded during flowering and maturity stages in both the study years. It was higher in 2009 than in 2008, this was linked to the higher precipitation in 2009. In 2008, despite there being rather less precipitation during the crop seedling stage than the later period of the growing season, water storage did not decline as evidenced by good availability of water in shallow well, and even slightly increased because maize consumes only a limited amount of water at this stage. During the rainy season i.e., from October to September, the spring maize takes up a great deal of water to maintain its luxuriant growth; the variation in seasonal soil water storage was, therefore, mainly affected by the amount of precipitation and maize growth for the given soil type. If quantity of soil water is considered; it is greatly influenced by the soil type. As a result, water storage decreased in 2008 but increased in 2009 during crop growth stages; during these stages the precipitation was 129 mm in 2008, compared to 215 mm in 2009. Mean soil water storage, calculated by averaging the readings taken at the sampled crop growth stages over the growing season, were much higher in the BBF mulched with maize straw under irrigation regime 1 (186 mm in 2008, 203 mm in 2009) than the non irrigated plots. BBF and maize straw mulching under irrigated condition significantly enhanced soil water storage in the 0-90 cm profile compared to the non irrigated plots.
The soil water content was significantly higher at the end of the cropping season in both the years than at the beginning in the 0-40 cm soil layer under each treatment, indicating water recharge in the soil over the crop’s growing season. However, the soil water deeper down the profile (60 cm) also occasionally changed under any of the treatments over the maize growing season due to high infiltration rate of the soil in the terraces. Runoff from terraces was rarely observed during rain. Since supplemental irrigation through drip laterals consisted of low volume of water, amplitude of cyclic variation of soil water was high only in top 0-20 cm soil layer and low in other layers, indicating that most of the water required by the plant was extracted from the top layer under irrigation regime 1 during initial growth stage. In some cases, the soil moisture content in 0-20 cm soil layer rose above the field capacity due to the occurrence of rainfall. The results also revealed that during the later stages of growth, when full development of roots was there, the plant also extracted some water from the lower layers i.e. 20-60 cm.

Under the irrigation regime 2, soil water was extracted from all the layers of the root zone; but most of the extraction was from 0-20 cm, 20-40 cm, and 40-60 cm soil layers. The irrigation regime 2 being a dryer regime as compared to regime 1, the magnitude of cyclic variation was higher in 20 cm and 40 cm soil layers as compared to similar layers in regime 1. The volume of water applied was lower under this irrigation schedule than that of regime 1.
The soil layer 60cm below the root zone remained unaffected. The water was lost through uppermost soil layer at a faster rate because of the evaporation from soil surface and transpiration from the grown up plants. Since the roots were developed enough after 1 month of sowing, the soil water was also extracted from 40-60 cm soil layer. The depth variation of moisture in the root zone (0-60 cm) was greatly influenced by the increasing crop water extraction at later growth stages. It was observed that the plants extracted most of the soilwater from 0-40 cm soil profile in case of maize. Therefore, it is inferred that only 0-40 cm of soil profile should be considered for scheduling of irrigation, for maize crop grown in sandy loam soil, in the region. According to Kamara (1986), reproductive stage marked the decline of soil moisture particularly at the 20-cm depth. As a result of increased evaporation and no rainfall, the 20-cm depth dried much more rapidly than the 50- and 100-cm depths. The decline in soil moisture during the reproductive period continued during the maturity/fallow period. The 20-cm depth reached minimum soil moisture. Because of the excessively dry top 20 cm, these soils will
require supplemental irrigation to support an existing crop with deep roots or double cropping with shallow-rooting crops. Supplementary irrigation for post-rainy season crop production is necessary, as suggested by Kanwar et al (1982).

5.3.5 Irrigation (Fig 54 & 55)

Farmers adopting micro irrigation systems are in control of flow rate, duration and frequency of irrigations. However, they may not be aware of the discharge when pressure variations occur in the supply system (Lamaddalena, 1997). Problems also arise when systems are not properly designed. These problems can be less when self compensating emitters are utilised. In this research, pressure variation along the drip laterals occurred due to friction loss and pressure variation due to land elevation is not pronounced since the laterals were laid on bench terraces which run along contour lines of the hill. So, non pressure compensating inline dripline was used for drip irrigated plots. When water was delivered from the upstream storage tanks by gravity, inlet pressure of manifold at each terrace varies about \(2\) m pressure head due to vertical interval of the terraces. So in each terrace, irrigation duration varies according to the variation of emitter discharge due to different operating pressures. This difficulty can be overcome by use of pressure regulators but it is very expensive for maize crop. As an alternative, plastic containers located at suitable elevation can act as pressure breaking chambers, can be provided from which each terrace can be supplied with water.

Most of the problems derive from inappropriate design and selection of equipment. These unfavourable conditions are often related to the fact that farmers are induced to adopt microirrigation systems to save water, without appropriate technical support. Microirrigation systems may use less water when application losses are minimized, but they should not be designed or managed for saving water. They should be managed to supply the water as required
by the crops with high frequency. Drip irrigation systems are normally used for frequent or very frequent applications, daily or twice a week. Under intensive crop production, more than one application per day may be necessary. Irrigation scheduling can be based on crop indicators or soil water status. For very frequent waterings, the irrigation, and fertigation strategies must be integrated, and are commonly based on the daily crop requirements.

Even though the effect of field water management practices on water storage was much less than the variations in precipitation, small effects on water conservation during the crop’s growing season could greatly affect maize yield as well as WUE. Supplemental irrigation improved both soil water storage and ET and, hence, significantly increased the grain yield. It is likely that irrigation after a soil drying cycle stimulated the physiological processes and caused compensation or over-compensation in plant growth and grain yield (Deng et al., 2006). However, the WUE did not exhibit consistent performance in both years under the upplemental irrigation treatment; it was lower in 2008 than in 2009 when the amount of supplementary water applied was reduced. It appears that additional irrigation supplementary when the soil water condition is optimal would have little effect on yield and may even be detrimental (Jin et al., 1999); in addition, excessive irrigation would enhance soil surface evaporation (Olesen et al., 2000), This could have caused the reduction in WUE in 2008.

5.3.6 Mulching and land configuration

The grain yield in the maize straw mulched plots was higher than that in the unmulched control plots. This was probably because straw mulching reduced soil evaporation augmented the infiltration of rainwater into the soil and enhanced soil water. However, the whole season average soil water storage and cumulative ET were nearly the same in the mulched and
unmulched treatments. It is likely that mulching increased the physiologically significant canopy transpiration (Raeini-Sarjaz and Barthakur, 1997; Wang et al., 2009); plant physiological processes were thus enhanced to ensure plant productivity and GY formation (Li et al., 2001; Li and Gong, 2002) compared to the unmulched treatment. In contrast, there was significant soil water depletion in the unmulched treatment. This is a result of soil surface evaporation, especially in the early growth stages. At this stage, most of the soil surface was exposed to the direct irradiation and a dry atmosphere; therefore, plant growth activities were notably restricted by water deficit, leading to reduction in WUE.

Straw mulching is regarded as one of the best ways of improving water retention in the soil and reducing soil evaporation (Baumhardt and Jones, 2002; Zhang et al., 2009). Effects of straw mulch on crop yield and WUE, however, have been variable, and this can be mainly attributed to differences in climatic conditions. The differences of yield and WUE between straw mulch and unmulched treatment were not appreciable in this experiment. These results are in agreement with recent investigations on straw mulch effects from temperate climates (Edwards et al., 2000). As pointed out by Do ring et al. (2005), mulching affects crop yields in many and complex ways. Higher yields under mulch have mostly been attributed to increased soil moisture under arid and semiarid conditions (Huang et al., 2005; Zhang et al., 2009); reduced yields under straw mulch have also been reported and have been attributed to below-optimum soil temperature, reduced soil nitrate levels, and mulching too early (Gao and Li, 2005). We conclude that the crop grain yield was sensitive to altered soil water conditions under different water management practices in the maize fields on the terraced hill lands of eastern Rwanda. Correspondingly, ET and WUE were also affected, resulting in differences in plant productivities. In the low precipitation area, the runoff is usually little, and most of the harvested
rainwater gathering at the surface is lost through evaporation. While the straw mulch covered land configurations particularly BBF and Compartment bunding (CB) would improve rainwater harvesting and subsequently increase crop yield. The findings suggest that farmers can adopt the maize straw mulching technologies to obtain the optimal effect in increasing crop yield and improving water use efficiency. Supplementary irrigation can have a substantial effect to increase crop yield, but farmers must consider its cost before using on a commercial scale.
Fig 51a Average Dry grain yield – Experiment 1
Fig 51c Average Straw yield – Experiment - 1
Fig 51d No. of Grains per row – Experiment 1
Fig 51e Number of grains 100 grams$^{-1}$ – Experiment 1
Fig 52c Stem Perimeter at different days after planting – Experiment 1
Fig 53a Crop growth rate at 30-60 days – Experiment 1
Fig 53b Crop growth rate at 60-100 days – Experiment 1
Fig 54 Irrigation demand and irrigation water applied during crop stages

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Fig 55 Rainfall and crop water demand at different crop stages
5.4 Effect of irrigation regimes and organic manure application

5.4.1 Growth and yield parameters (Fig 59a to 59c)

All the growth parameters like plant height stem perimeter and LAI were observed high in plots which received higher organic manure dose and good supplemental irrigation by basin irrigation followed by drip irrigation. Similar trend was followed in both the years but growth parameters were marginally high in the second year whereas yield components were better in the second year due to the influence of good rainfall in the second year from flowering and maturity stages. Soil organic matter is one of the important soil properties that may considerably influence the activities of soil enzymes (Gianfreda and Bollag, 1996). Solid organic amendments could enhance soil enzyme activities by increasing soil organic matter and thus the microbial biomass (Crecchio et al, 2004; Acosta-Martinez and Harmel, 2006). In terms of growth, yield and soil moisture retention, basin irrigation with 120mm irrigation under organic manure application of 15 tons per ha performed better than drip irrigation with laterals spaced at 120cm and applied 15.3mm supplemental irrigation under no application of soil organic manure. This implies the role of soil organic manure to enhance soil water availability to influence growth and yield of the crop. Water balance in 90 cm soil depth during the crop period implies that basin irrigation used just 4 percent higher water under deficit irrigation with soil organic manure dose of 15 tons per ha, than drip irrigation with laterals spaced at 120 cm under no organic manure application. This indicates that soil organic manure application reduces deep percolation loss in basin irrigation and also improves water retention. There was a quite good variation in straw and grain yield which may be attributed to spacial distribution of available soil organic matter within the terraced area. In general Rwandan hilly terrains exhibit lower soil organic manure in the hill top to middle and slowly increasing towards the bottom of the hill reaching maximum in the
swamps. This is due to the general phenomena of loss of soil organic matter due to runoff water from rainfall. When soil organic matter is high it influences soil physical properties and reduces deep percolation loss but on the other hand it results in water logging condition of root zone if more water is applied with less frequency. So possibility of root zone aeration problem occurs in basin irrigation and the degree of the problem is directly proportional to the soil organic matter. But in hill terrain like Rubirizi, the soil infiltration rate is very high and it may leads to more water loss by deep percolation, under such circumstances drip irrigation with high frequency of application is preferable wor better water use efficiency. Use of organic fertilizer alone at reasonable rates could sustain maize yield at a limited level, therefore to increase crop production to a sustainable level both organic and inorganic fertilizers are needed (Vanlauwe et al., 2001). As it was also reported by FAO (1999) that organic fertilizer are there to maintain soil physico-chemical conditions which can influence grain yield.

5.4.2 Soil moisture

Effective soil water content ranged from 14 to 20.6 per cent in the surface layer of soil in plots received 15 tones per ha of organic manure and higher irrigation dose under basin irrigation. Basin irrigation treatment led to the highest water retention than the other irrigation treatments. Organic manure treatment led to significant increase of water content than other treatments. The role of soil texture in soil water properties is well defined particularly the positive relationship between soil fine particles content and water holding capacity. The water holding capacity is inversely proportional to the sand content. Many researchers have observed these correlations between soil texture and moisture contents of soils (Saxton, 2003). The more the content of soil fine particles (clay and silts) higher the water-holding capacity of the soil (Mathieu and Pieltain, 1998). Since the soil of the research plots have much course sand particles
high doses of animal manure increased soil moisture content. Saxton (2003) and Gupta and Larson (1979) also reported that organic matter contributes to high retention of soilwater. Its role as a soil structure stabilizer is also well known (Koussoube', 1978; Ouattara, 1994). The useful available water capacity is less than those reported in the literature for this soil type, estimated at 1 mm for 1 cm of soil depth (Dembe'le' and Some', 1991). Ouattara (2000) showed that soil water evaporation on plots fertilized with organic manure was lower than those without manure application. This was due to the water retention and protection of the soil by the biomass on the plots, which received organic manure.

5.4.3 Supplemental Irrigation

The crop water demand has been assessed by using the Kanombe meteorological data. Irrigation was given based on tensiometer reading which maximum soil moisture tension reached up to 72 centibars. Periodic analysis of crop water demand and effective rainfall indicates a total deficiency of 203.5 mm which has to be supplied by irrigation. Taking 60 percent as overall efficiency for basin irrigation system, actual water to be delivered to the field is 339.2 mm. Even though cropping was continued up to 28th February, irrigation was not needed in that month because of crop stage and adequate rainfall. Under irrigation 1c (basin irrigation), 35.4 percent of the irrigation demand was supplied for irrigation interval of two days; 17.7 percent of irrigation demand was supplied for irrigation interval of three days and 13.3 percent of irrigation demand was supplied for irrigation interval of 6 days. Under irrigation with one lateral per row of crop (L), 30.2 percent of the irrigation demand was supplied for irrigation interval of two days; 16 percent of irrigation demand was supplied for irrigation interval of 4 days and 12 percent of irrigation demand was supplied for irrigation interval of 6 days. Under irrigation with one lateral per two rows of crop I3, 15.4 percent of the irrigation demand was supplied for irrigation interval of two
days; 8 percent of irrigation demand was supplied for irrigation interval of 4 days and 6 percent of irrigation demand was supplied for irrigation interval of 6 days.

5.4.4 Grain Yield (Fig 58a to 58e)

The maximum mean yield of grains was 5.4 T ha\(^{-1}\) in basin irrigation plot applied with 5mm once in 2 days and lowest grain yield of 3.1 T ha\(^{-1}\) was obtained in drip irrigation of one lateral for two rows applied with 3.4mm once in 6 days under organic manure of 15 T ha\(^{-1}\). Lowest yield of 2.8 T ha\(^{-1}\) was obtained under drip irrigation of one lateral for two crop rows without organic manure application when supplemental irrigation was given at 3.4mm once in 6 days.

Statistical analysis of data on the yield of dry grains shows that there is significant difference at 1 percent level among all the treatment as well as their combination effect except that of irrigation method and organic manure. Basin irrigation performed well followed by drip irrigation with one drip per row of crop. Drip irrigation with one lateral for two rows of crop is the least performed irrigation method in terms of grain yield. Among irrigation water quantity, plots received water once in two days performed well and water application once in 6 days performed poorly in all the irrigation methods but this is obvious. Organic manure application of 15 T ha\(^{-1}\) performed well followed by 7.5 T ha\(^{-1}\).

The grain yields obtained in basin and drip irrigation with laterals spaced at 60cm under organic manure manure application of 15 T ha\(^{-1}\) are above the average yield of short duration varieties yielding 2 to 3 tons per ha and above 4 T ha\(^{-1}\) set as an international minimum maize yield standard by FAO. This means that an adoption to the current research findings can improve maize productivity by almost 50 percent for smallholder winter maize in the study area. Mtambanengwe and Mapfumo (2006) reported between 24 percent and 104 percent increase in
grain yield under mineral N–organic manure combinations. It was also reported that the most promising route of improving inorganic fertility is adding of small amounts of high quality organic matter to tropical soils and provide a 2:1 ratio (inorganic to organic) to improve productivity and provide irrigation schedule of 40 mm every 7 days or water balance schedule at 40 percent depletion.

5.4.5 Irrigation water use efficiency (Fig 60)

IWUE under basin, drip with 60cm lateral spacing and 120cm lateral spacing irrigation systems were 10.8, 14.9 and 19.2 Kg m$^{-3}$ in the first year and 11.9, 13.7 and 16.4 Kg m$^{-3}$ respectively in the first year under organic manure application of 15 tons per ha. By adopting drip irrigation with laterals spaced at 60cm, average of 54 percent water saved for 19.6 percent yield reduction and 75 percent of water saved for 33.6 percent yield reduction in case of drip laterals spaced at 120cm in comparison with basin irrigation in the first year and in the second year marginally lower values was observed due to increased irrigation water application. This shows that farmers can save water by adopting drip irrigation and soil organic matter augmentation. Under all the irrigation methods, augmentation of soil organic matter was a good indication of increased productivity of water. Under the emergence of water scarce situation, drip irrigation has the great potential for increasing land and water productivities.

Highest average irrigation water use efficiency of 17.5 Kg m$^{-3}$ has been obtained under drip irrigation with one lateral for two rows of maize. This is because of high application efficiency compared to other methods of irrigation. Comparatively higher production has been observed in plots irrigated by flooding but irrigation water use efficiency is very low compared to other methods due to poor application efficiency. Results obtained are in agreement with that obtained by Jose et al (2008) who reported IWUE of 21.08 and 4.13 Kg m$^{-3}$ based on dry maize
grain was obtained under supplemental irrigation of 22 and 226mm under drip irrigation. Karam et al. (2003) reported that stressed plants have higher WUE values than well-watered plants. This in increase in efficiency is due to a larger decline in plant transpiration because of reduced green leaf area as a consequence of water stress, which has probably also reduced the evaporation from the dry soil.

5.4.6 Yield Response To Supplemental Irrigation (Fig 56, 57a to 57c)

Dry grain yield reduction obtained with respect to the yield in basin irrigation with 5mm water application once in two days, are analysed for all treatment combinations with 15Tons ha⁻¹ organic manure application. In one drip lateral per row when 3.4mm irrigation applied once in 6 days, maximum of 74.8 percent irrigation water can be saved for 27.8 percent yield reduction compared to check basin irrigation of 5 mm once in two days. Under water scarce conditions, it is recommended to use drip irrigation with laterals spaced at 120cm and apply 3.4 mm water once in six days from flowering stage of crop under organic manure dose of 15MT per hectare to achieve maximum water use efficiency by practicing deficit irrigation. In one drip lateral per two rows of plant, for example maximum of 83 percent water can be saved with 32.4 percent yield reduction and different values were obtained for different irrigation regimes. These informations should be analyzed with investment cost saving against one lateral each plant row. If sufficient water is available to go for basin irrigation, 5mm water application once in 4 days can save 50 percent water with just 3.2 percent yield reduction.

Yield data obtained can well fit into quadratic equation. This is in agreement with Quadratic fit between irrigation and grain yield as obtained by Jose et al (2008). These quadratic equations represent the characteristic feature of the three irrigation methods in terms of grain yield response to irrigation water under soil and climatic conditions of Rubirizi. It is observed
that for drip irrigation the relationship has comparatively more slope on linear fit infering grain yield is more sensitive to irrigation water under drip irrigation than basin irrigation.

\[ y = 4.739 + 12.526x - 0.067x^2 \]  
**I_1**

\[ y = 446.073 + 1.815x - 0.006x^2 \]  
**2009**

\[ y = 404.027 + 2.214x - 0.016x^2 \]  
**I_2**

\[ y = 477.104 + 0.942x - 0.004x^2 \]

\[ y = 402.16e^{(-4.447/x)} \]  
**I_3**

\[ y = 276.643 + 3.835x - 0.030x^2 \]

**Fig 56a Relationship between Irrigation water and Dry grain yield under M3**
Fig. 56b Relationship between Irrigation water and Dry grain yield under maize straw mulch (M2)
Fig 57b Yield response to water reduction under M2
Fig 57c Yield response to water reduction under M3
Fig 58c Average Straw yield – Experiment 2
Fig 58d No. of Grains row$^{-1}$.
Fig 58e Number of grains per 100 grams – Experiment 2
Fig 59a Plant height at different DAP – Experiment 2
Fig 59b Leaf Area Index at different Days after planting – Experiment 2
Fig 59c: Stem Perimeter at different days after planting – Experiment 2
Fig. 60 Irrigation water use efficiency under different irrigation regimes
5.5 Cost analysis (Fig 61a, 61b, 62 and 63)

From former’s perspective, the net returns from the crops should be maximum. Net return from the crop is the difference between the gross return and farming cost. The farming cost mainly includes the cost of inputs such as: labour, water and fertilizer. The water cost for each irrigation treatment was calculated by multiplying the cost of unit volume of water and the total quantum of irrigation water required for the maize crop. The main source of the irrigation water was the ground water. The gross return has been calculated by multiplying the total yield in tons per hectare and market price of maize per tonne (Kumar and Pathak, 1989). If maize is sold as dry grains it will not be feasible for drip irrigation. Since there is much demand for fresh cobs, it is also considered as benefits as an alternative to dry grain in cost analysis. Maize straw mulch with BBF, RF and CB under different irrigation regimes are considered for cost analysis in case of the first experiment. Operation cost includes cultivation and irrigation cost whereas capital cost includes drip irrigation system, water pump, shallow well and HOPE lined water storage tank.

For the first experiment, Benefit cost ratio is less than one in all the treatments for both the years of the study. Even though irrigation regime and mulching had significant effect of dry grain yield, the project is not feasible mainly due to low market price for dry grain maize. Since dry grain maize is mostly used as animal feed and used for human consumption during food crisis. This low market price makes the capital investment mainly on drip irrigation using ground water system non feasible. Even without supplemental irrigation, maize cultivation is not feasible in the newly formed low productive soil in Rubirizi. The expected yield of 6 tons per hectare is not achieved with the long duration high yielding variety of maize. Moreover the cost of cultivation is very high due to high labour cost influenced by high living cost in Kigali city. So,
maize cultivation with high yielding long duration variety of maize like POOL 9A is not feasible with supplemental irrigation system. The best way is to go for rain fed cultivation using short duration variety of Kathumani. The second option of selling fresh cob is considered for economic analysis. It shows that average BCR of 1.6 can be achieved with irrigation regime 1 and this can pay back the investment cost on drip irrigation infrastructure in 9 years. So considering the huge demand of fresh maize cobs for direct human consumption, the maize production should be sold as fresh maize cob to make the maize cultivation under supplemental irrigation with drip irrigation system an economically feasible and profitable venture. The profitability still can be increased if maize cultivation is carried out to yield in peak demand months like November, December, March, April, June and July when the fresh maize is not available. During these months fresh maize cobs can fetch high price. The research further demonstrates that maize cultivation can be carried out throughout the year provided irrigation water supply is made available.

In the second experiment which was conducted in the downhill terraced land under different organic manure applications under supplemental irrigation shows that maximum BCR was obtained in basin irrigation followed by drip irrigation with 60cm and 120 cm spacing considering sale of dry grains. But feasibility is observed only in basin irrigation and limited to 7.5tons ha$^{-1}$ of farm yard manure. Since cost of farm yard manure is high it has significant influence in reducing BCR. Application of farm yard manure at the rate of 15tons per hectare is not feasible under supplemental irrigation. If farm yard manure is available free of cost, and then adoption of basin irrigation system for supplemental irrigation is feasible if the produce is sold as dry grains. For the case of selling fresh cobs, 1.7 and 2.4 are obtained for basin and drip irrigation system with farmyard application of 7.5tons per hectare. Application of 15tons per
hectare farmyard manure reduces the BCR in all the irrigation methods because of increased cost and in case of drip lateral spacing of 120cm it is not feasible. This is due to low quality of maize cob which fetches low market price. Hence it evident that for non commercial crop like maize, supplemental irrigation adopting expensive drip irrigation with ground water becomes if it is marketed as fresh cobs which is in much demand for human consumption throughout the year in Rwanda.
Fig 61a Benefit cost ratio based on sale of dry grain yield – Experiment 1
Fig 63 Benefit cost ratio based on sale of fresh cobs – Experiment 2