Effect of runoff management and soil conservation practices on the growth and yield of Maize (Zea mays) in a sub-humid agro-climatic zone of Ile-Ife, Nigeria

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Abstract: Field experiments were conducted at the Teaching and Research Farms, Obafemi Awolowo University, Ile-Ife in a completely randomized design with five soil-water conservation (SWC) treatments: Contour bunds (CT); Infiltration pits (IP); Mulched plots (ML); Tied ridges (TR); and the Conventional practice (CP), which served as the control. Four (4) levels of soil moisture replenishment [50% (Full Replenishment), 25% (½), 12.5 % (¼), and 6.25 % (1/8)] after depletion to 50% of Field Capacity (FC) were considered as supplementary water application from an in-situ RWH system. Measurements of soil moisture in the soil profile, plant growth parameters and yield at harvest were made. Results showed that maize yield and WUE varied amongst the SWC practices and within the years from the experimental plots with substantial yield improvements. The TR and CT gave better yields compared with the ML and IP of the same year. The 50 and 25% replenishment levels under TR and CT also gave better yield and WUE compared with other levels of replenishment. Biomass yield for the 2008-2010 planting seasons recorded higher values in TR, IP and CT compared to the control experiment, while the moisture retention ability was better in TR and slightly lower in CT of the same year. In 2011 soil moisture replenishment, the 50% gave the highest yield in a TR, followed by the CT and ML treatments. The TR gave the best WUE for the 50% and in all cases the CP gave a comparatively low efficiency. The study concluded that the methods of soil moisture conservation practice is an effective way to increase water availability for higher crop yields; but a combination of the supplementary, in-situ RWH system could produce better results in terms of enhanced yield and mitigate against the adverse effect of short duration intra-seasonal drought.

1. Introduction
Eighty per cent of the agricultural land world-wide is under rain-fed agriculture, with generally low yield and high on-farm water losses. Agricultural systems in Nigeria are mainly resource poor, rural-smallholder-farmer-oriented and also predominantly rainfed. Nigeria, though endowed with abundant rainfall experiences seasonal water shortages and dry spells during the cropping season which eventually
affects total crop yield. Intra-seasonal scarcity of water is a major and critical limitation to increasing and improving productivity of traditional rainfed farming in Nigeria.

The high intensity rainfall produces significant runoff because of the low infiltration rates of the soils, leading to reduction in yield; crop failure; erosion and soil degradation. Studies in many of the rainfed areas and drought-prone environments have shown that meteorological dry spells are important causes of low yield [1-3]. Even during the periods of high seasonal rainfall, if the interval between consecutive rain events is too long it may cause total pasture and crop failure [4,5]. The overdependence on rain and the continuous effect of climate change has brought a great limitation to rainfed agriculture in Nigeria and there is therefore the need for a paradigm shift to a more suitable and effective alternative of rainwater/runoff harvesting, harnessing and usage.

Seasonal water shortages, dry spells (periods of 2-4 weeks with no rainfall) at critical stages of crop development has resulted to adverse effect on crop yields. The freshwater shortages of the world result more from uneven distribution of water over time and space than from absolute scarcity. Even in some of the highest rainfall areas, rainfall occur in concentrated periods followed by prolonged dry spells while in some of the driest areas, occasional intense rainfall generates higher runoff volume. Water-related problems in the tropics are often related to high-intensity rainfall with large spatial and temporal variability, rather than to low cumulative volumes of rainfall [6-8]. The overall result of unpredictable spatial and temporal rainfall patterns indicates a very high risk for meteorological droughts and intra-seasonal dry spells whose impact on rain-fed agriculture is complete crop-failure, which statistically, for semi-arid lands, occurs about once every 10 years [9].

There is a growing scarcity and inter-sectoral competition for water viz: domestic, agricultural and industrial along with groundwater depletion, population increase and the adverse effect of climate change. Hence, there is the need for farmers to re-evaluate usage of the available water, consider alternative sources of water i.e. rainfall-runoff water and make judicious use especially during the time of scarcity. The challenge of feeding the increasing world population in the face of the adverse effect of climate change depends to a large extent on improved agricultural water-use within the present land/water-use systems and presently rain-fed agriculture plays a significant role in this regard. Ninety-five per cent of the current population growth occurs in developing countries and most particularly; sub-Saharan Africa, hosting the largest proportion of water scarcity-prone areas as well as the highest level of malnutrition [10]. The increase of population and urbanization in developing countries, coupled with the recent evidence of climate change, may result to insufficient water to meet the urban population demand [11-15].

Maize (Zea mays L.) is considered as one of the most popular grain crops grown in Nigeria because of its domestic and industrial uses. In recent years, efforts have been made by the IITA in developing new crop varieties and establishing seed multiplication stations across the various zones in Nigeria. However, higher yields can still not be ensured due mostly to dry spells, insect infestation, and unpredictable weather condition. The current effort is on on-farm rainwater/runoff concentration practice to improve corn production in the savannah belt of Nigeria.

Apart from the introduction of cultural practices to improve on soil nutrients by replenishment with time, attempts were made to improve crop yield with the Fadama farming systems. With the attendant poor crop performance, low crop yields and sometimes total crop failure of the Fadama; the collection, diversion and/or short-term storage of runoff towards the dry-spell period are very critical for farmers in Nigeria [16]. The impact of drought stress on crop productivity is particularly severe when the drought coincides with the moisture-sensitive stage of the crop and if farmers have no management alternatives to overcome the problem [17]. There are many physical soil and water conservation structures for retaining surface runoff in the field and thereby altering the soil water status within the root zone [18-22].

According to the Food and Agriculture Organization [17], crop yield can be significantly increased if cost-effective field water harvesting technologies are used. Various forms of improving rainwater/runoff harvesting and usage can help to retain water in-situ by minimizing runoff and bringing more water to crops by maximizing infiltration [1,3,22-24.]. Previous efforts by researcher on RWH
with fieldworks to test the various techniques in different semi-arid areas include the works of [8,22,25-28]. The various in-situ methods of SWC which are effective ways of increasing water availability for higher crop yields have not been tried with supplementary RWH systems in Nigeria. Harnessing and diverting these runoffs to agricultural fields in a controlled manner could help to meet the deficit of the dry spell, supply water during the intra-seasonal shortages, and ensure adequate replenishment of the soil water. It would also reduce erosion, soil-nutrient depletion and soil degradation problems. Therefore, rainwater harvesting for agriculture is considered crucial in this regard.

2. Materials and methods

2.1 Description of the study area

The field experiments were conducted at the Teaching and Research Farms of Obafemi Awolowo University, Ile-Ife, Nigeria between 2008 and 2011. The experimental site is located on latitude 07° 28’ 0” and longitude 04° 34’ 0” at 271 m above the mean sea level [29]. Ile-Ife is in the sub-humid (SH) agro-climatic zone of Nigeria. The experimental site was a dense vegetation since the land has been left to fallow for four years. The land was ploughed twice, harrowed once after which the land was laid out for experimentation. Soil sampling was done before ploughing by using a soil auger. Ten soil samples were randomly collected at 0-50 cm depth from the study site for analysis. Samples were bulked and the dried sample sieved through a 2 mm aperture sieve. The samples were analysed for bulk density, moisture content, porosity, infiltration rate and organic matter content. The soil textural classification was determined. Quality protein maize (QPM) ‘Obatanpa’ was obtained from IITA Ibadan, Nigeria. The seeds were treated with pre-planting insecticide with active ingredients: 20% w/w thiamethoxam, 20% metelaxy-M and 2% w/w difenoconazole. Seed sowing was done following the recommended number of 2 or 3 seeds per hole, spacing and plant population immediately after the onset of the rains. The application of pre-emergence herbicide - a systemic herbicide with Altrazine + metolachlor at the rate of 270g/150l was applied immediately after seed sowing. Subsequently, selective herbicides were applied to control the growth of weeds and weed seeds. Mechanical control (weeding) was also used when necessary since this is also the tradition in the study area.

2.2 Rainfall and dryspell analysis of the study area

Rainfall and dryspell analysis of 19-year rainfall data obtained from the weather station at the Teaching and Research Farms were done. The analysis for the occurrence of abrupt changes and trends using the Pettitt and the Mann-Kendall tests were used [30]. Variables analysed, which are major rainfall indicators includes annual total rainfall, total number of rain days, rainy season onset/cessation dates, intra-seasonal distribution of rain events, lengths of intervening dryspells, termination and duration of the rainy season as well as monthly rainfall, and monthly number of rain days.

The average duration of dryspells were estimated for the study site from the long-term rainfall probability parameters. This rainfall data established the duration of the longest agricultural dry spell to be used in a simple water balance model describing the impact on maize as the test crop.

2.3 Experimental design

Four field experiments were carried out during the period 2008-2011 in both the early and late maize planting seasons at the Teaching and Research Farms, Obafemi Awolowo University (OAU), Ile-Ife. The experimental plot for the 2008-2010 year was a completely randomised split-plot type with four treatments viz: Contour bunds (CT); Infiltration pits (IP); Mulched plots (ML); Tied ridges (TR); and the Conventional practice (CP) as the control. Each experimental plot measured 4 by 5 m (20 m²) with a plant population of about 150 stand per plot. The entire area was divided into 30 sub-plots and each technique replicated three times so as to block out some effects such as slope, topography of the area, uneven distribution of nutrients, soil texture and organic matter content variations. Each sub-plot was
separated from the other by an alley of 1-1.5 m to minimize the effect of interference of each technique with the other and also for ease of movement while taking measurements.

The 2011 field experiment involved the introduction of four (4) levels of soil moisture replenishment after 50% soil moisture depletion from Field Capacity (FC). This was with a view to maintaining the soil at different moisture regimes after the depletion. The treatments were also completely randomized in a split-plot design within the conservation practices. The runoff used after soil moisture depletion was collected in dugout trenches located round the experimental plots. The choice of the location of each pit was guided by the natural water path and the terrain/slope of the plot. Each dugout trench (18 in №) was 75 cm in radius and 90 cm deep and adequately compacted (Plate 1).

Desilting was done at intervals so that adequate volume of water could be collected. The trench-lines linking these dugouts trenches were also cleared of debris, deposited sand/earth materials and the embankments sometimes reconstructed. Water application was done in form of water sprays like in simulated rainfall.

Plate 1. (a). Typical compacted dugout hole and the linking trenches for runoff collection. (b). Control of external runoff contribution into the experimental plot

2.4 Experimental methods
Five different in-situ soil moisture conservation treatments were investigated viz:
The Contour bunds (CT) system consists of semi-circular earth-bunds embankments of radius 1.5 m and 45 cm high constructed along the contour lines to act as barrier to the flow of water and to increase water detention time thereby enhancing infiltration [31]. The embankment traps the water flow behind the bunds allowing deeper infiltration into the soil while the Infiltration pits (IP) are 15 by 15 cm square deep trenches dug along the row of the plant-stand, filled with grasses, plant residue, stubbles or stover and covered back by a thin layer of soil. This is also to trap direct rain falling on the field and thereby increasing infiltration within the root zone depth. The mulched plots (ML) involves covering of the soil with crop residues, leftovers on the field and dried grasses to minimize water loss through evaporation and also aid water detention time. Covering percentage of about 70-75% is recommended with elephant grass (*Pennisetum purpureum*) [32]. The grass is readily available in the study site selected for this experiment and it is of little -known economic value. The Tied-ridges (TR) consists of 45 - 60 cm high earth ridges made across the slope at a row spacing of about 0.8-1 m. The ridges are tied at both ends and at mid-points (at heights less than that of the main ridge) with 45-50 cm high mounds along the furrow so as to concentrate runoff and rainfall along the furrow. The Conventional practice (CP) (control with which all other treatments were compared) involves planting of maize on a relatively flat land which is the most common practice in the study area after ploughing and harrowing. In CP, planting is done on a coarser and partly debris/straw incorporated farm-field.

2.5 Measurements and data collection
The soil moisture content, daily rainfall, plant growth and yield at harvest were measured. Measurements of the root-zone soil moisture variations at 15 cm depth were done for each subplot weekly and also after each rainfall events. This was done both gravimetrically and by using a Field Scout TDR 100 Soil Moisture Meter (Spectrum Technologies, Manchester, UK) (Plate 2). The working principle of the meter is based on a Time-Domain Reflectometry with an accuracy of ±3.0 % volumetric water content (VWC) and electrical conductivity of less than 2 dS m$^{-1}$, for quick and accurate determination of VWC in soils. The daily rainfall measurements were taken using a rain gauge and also recorded data from the weather station at the Teaching and Research Farms. Other weather data obtained from this weather station (Vantage Pro2 TM, Davis Equipment) are: daily maximum and minimum air temperatures, relative humidity, and wind speed at 2 m height, net solar radiation, vapour pressure, sunshine hours and rainfall amount. Growth indicators such as plant height, stem girth, leaf area, number of leaves, canopy cover (CC); and yield parameters (average number of cobs per plant, grain and dry matter yield at maturity) were also measured. The above ground height of the plant shoot from each subplot was measured linearly once every week to determine the growth rate of the plant under the different treatments or conservation practices. The plant stem girth/diameter at the base of the plant just above the highest adventitious root-outgrowth was also measured with a vernier calliper weekly. The leaf area index (LAI) and canopy cover determined using AccuPAR LP 80 (Decagon Devices Inc, Pullman). Other agronomic parameters such as average number of leaves/plant and average number of cobs/plant, etc were measured. The grain and biomass yield was measured at maturity. Grain yield was measured by weighing the harvested cobs per plot at maturity. This was when safe level of grain moisture for storage (12-13%) was achieved on the field. The biomass produced, which was the above-ground remaining stalk, was also measured by weighing.

2.6 Statistical analysis of experimental data
Data collected were analysed using descriptive and inferential statistics. Data from 2008-2010 experiments were subjected to statistical analysis using Statistical Analysis System (SAS). Analysis of variance (ANOVA) was performed to compare the effect of SWC treatments on grain and biomass yield. Duncan’s multiple range tests was used to establish the differences among treatments.

3. Results and discussion
3.1 Results of soil physical properties
The soil after analysis is found to be of the “Apomu” soil series. The “Apomu” soil (Inceptisols) consists of 67.7% sand (>20 μm), 15.3% silt (2–20 μm), 17.0% clay (<2 μm) and 2.16% organic matter [33].
The dissolved cation showed on the average 0.14, 0.17, 1.31 and 0.9 cmol/kg for Na\(^+\), K\(^+\), Ca\(^{2+}\) and Mg\(^{2+}\), respectively, while the pH was 6.5. The textural class of the soil in this study area is predominantly sandy loam, with a very high percentage of sand at the different depths in the soil profile. The average bulk density is 1.52 g m\(^{-3}\) and the value increases as the depth increases in the profile. The results obtained from the soil properties are similar to previous work on this same study sites \[34-36\]. Soil textural classification and dissolved cations for the two experimental site locations up to a 50 cm depth was determined.

3.2 Rainfall for the seasons and dryspell analysis
Rainfall measurement for the four seasons is as recorded in Table 1. Total rainfall of 663.30, 865.70, 684.80 and 722.20 mm were recorded in the 2008, 2009, 2010, and 2011 seasons while 986.20, 1168.10, 1020.40 and 1387.80 mm were the total annual for the years, respectively (Table 1). The study site is located in a rain forest which experiences approximately eight months (March-October) of bimodal rainfall. It has about four months of dry season with slight irregularity in the rainfall distribution pattern. The total rainfall in each of the planting seasons showed a high percentage of the total compared with the remaining days outside the cropping season. The year 2008 rainfall gave the least amount for the actual cropping season which may be responsible for the generally low yields for that year.

The year 2011 was regarded as the wettest year with total rainfall of 1387.80 mm but with 52.02% of the rainfall occurring in the cropping season compared to 67.26, 74.11, and 67.11% of the total rainfall in the 2008, 2009 and 2010 cropping seasons respectively. For the seasons most especially in the early maize planting periods (2009 and 2011), rainfall total was adequate but inadequately distributed over the growing season even though 74.11 and 67.11 % of the rainfall amount occurred during the cropping seasons. The uneven distribution and higher runoff percentage among other things may contribute to the low yields. The rainfall data for Ile-Ife showed an average rainfall of approximately 235 mm and a relative humidity of 74.2% with a bimodal rainy season beginning in April and ending in October. The late maize planting periods were characterised by short duration dry-spells in the months of August.

The dry spell analysis showed the significance of the August break. This is because the probability of dry spells of more than 10 days and more than 15 days not occurring in the cropping season can be seen to be much higher than for the other months within the rainy season. The probability of non-occurrence of dry spell of greater than 10 and 15 days in the month of August was 71 and 88 % respectively while that of non-occurrence in > 5 days in the same month was 23% in the study area (Table 2). Analysis of the monthly moisture balance (Fig. 1) showed the occurrence of moisture deficit for the period of late October to late March. However, if the balance is computed for effective rainfall instead of total rainfall, then the surplus is seen to be much less and a deficit occurs in the latter part of the rainy season which clearly underscore the importance of the runoff and soil and water management scenarios that will improve soil-water infiltration. This is similar to previous studies reported in literature in Erin-Oke and Erin-Ijesha axis of Osun State \[37-38\].

| Year   | Total rainfall (mm) | Measured rainfall for the cropping season (mm) | % of rainfall total in the cropping season |
|--------|---------------------|-----------------------------------------------|------------------------------------------|
| 2008   | 986.20              | 663.30                                        | 67.26                                    |
| 2009   | 1168.10             | 865.70                                        | 74.11                                    |
| 2010   | 1020.40             | 684.80                                        | 67.11                                    |
| 2011   | 1387.80             | 722.20                                        | 52.04                                    |

| Dry spell period (days) | Jan | Feb. | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------------------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Probability of occurrence (%) |     |      |     |     |     |     |     |     |     |     |     |     |
> 5 days & 100 & 95 & 83 & 66 & 64 & 48 & 66 & 77 & 36 & 65 & 88 & 100 \\
>10 days & 83 & 78 & 38 & 8 & 0 & 0 & 11 & 29 & 11 & 18 & 79 & 76 \\
>15 days & 76 & 48 & 14 & 5 & 0 & 0 & 3 & 12 & 0 & 3 & 56 & 72 \\

Mean of 19 year rainfall data used for the analysis

| Months | Rainfall | Actual ET | Potential ET | Eff. Rainfall |
|--------|---------|-----------|--------------|---------------|
| Jan    | 250     | 150       | 100          | 50            |
| Feb    | 200     | 120       | 100          | 20            |
| Mar    | 150     | 90        | 80           | 10            |
| Apr    | 100     | 60        | 50           | 0             |
| May    | 50      | 30        | 20           | 0             |
| Jun    | 0       | 0         | 0            | 0             |
| Jul    | 0       | 0         | 0            | 0             |
| Aug    | 0       | 0         | 0            | 0             |
| Sep    | 0       | 0         | 0            | 0             |
| Oct    | 0       | 0         | 0            | 0             |
| Nov    | 0       | 0         | 0            | 0             |
| Dec    | 0       | 0         | 0            | 0             |

Figure 1. Moisture Balance for the Study Area (mean of 19-year data)

3.3 Soil moisture storage variation
Weekly measurements of average soil moisture content were recorded with a TDR moisture meter. There were significant variations (P≤ 0.05) in the volumetric water content (VWC) according to the soil moisture conservation methods on each sub-plots. The TR had a higher VWC, when compared with CP because of the higher water detention time when the ridges were tied. [39] concluded that tied ridging gave significant improvement in yield obtained from tomato under this similar condition over a no tied ridge condition. This is also similar to the conclusion reported by [2] that dry-spell mitigation can be effective with SWC especially tied-ridge and contour bunds. The water in the CP conservation methods infiltrates very rapidly and the coarse/no-till nature of the top soil also contributed to the rate of infiltration. The CT moisture conservation methods also showed a good level of surface water retention and on the average these treatments retained water better than CP. Average soil moisture content for each of the treatments is as shown in Table 3.

3.4 Growth parameters
The mean plant height, leaf area, stem girth, average number of leaves and cobs per plant were measured. Plant height which is the above ground shoot length varied between 1.01 and 2.14 m at harvest. The CP in most cases had the least height in the years while the CT had the highest height measurement in the
2008 and 2010 cropping season. Mean variation in plant height at maturity is as shown in Table 4. The variations monitored weekly generally showed TR and CT to be taller than the CP of the same year. The average leaf area (cm$^2$) and the stem diameter showed that CB and TR produce leaves with longer midrib, and broader area than the CP and IP in most of the cropping season. The leaves showed no sign of chlorophyll deficiency due to the moisture retained and made available to the plants during the early stages of vegetative growth by the treatments on these plots. The mean stem diameters (girth) is as shown in Table 5. At 5 WAP, CT and TR showed higher values of stem girth which is an indication of good vigour; better plant-root anchorage and this may be responsible for a better water uptake by the plants. This trend was also noticed at 10 WAP where stem girth was in the decreasing order of CP < ML < IP < TR < CT for most

Table 3. Average Soil Moisture Content (%) for the Treatments

| Year                  | Year | WAP | DAP | CT  | IP   | ML   | TR   | CP  |
|-----------------------|------|-----|-----|-----|------|------|------|-----|
| 2008 (late season)    | 2    | 14  | 25.1| 22.7| 19.7 | 27.3 | 14.4 |     |
| (Sowing date - July 21) | 3    | 23  | 11.9| 13.7| 13.3 | 15.4 | 12.2 |     |
|                       | 4    | 28  | 20.9| 17.2| 19.8 | 22.9 | 15.2 |     |
|                       | 5    | 37  | 16.9| 13.1| 10.1 | 16.8 | 11.3 |     |
|                       | 6    | 43  | 25.3| 23.6| 18.9 | 29.4 | 15.6 |     |
|                       | 7    | 50  | 25.6| 19.7| 15.9 | 21.5 | 14.6 |     |
|                       | 8    | 57  | 25.4| 28.8| 22.8 | 27.6 | 25.2 |     |
|                       | 11   | 78  | 24.3| 20.7| 21.7 | 31.3 | 21.0 |     |
|                       | 11   | 79  | 19.7| 19.0| 17.3 | 18.7 | 14.7 |     |
|                       | 12   | 87  | 23.3| 18.7| 19.0 | 24.0 | 16.0 |     |
| 2009 (early season)   | 2    | 14  | 25.0| 22.7| 23.5 | 25.9 | 10.9 |     |
| (Sowing date April 19)| 3    | 21  | 15.3| 14.3| 15.2 | 15.4 | 12.2 |     |
|                       | 4    | 28  | 23.0| 17.0| 21.1 | 20.9 | 15.3 |     |
|                       | 5    | 35  | 19.9| 14.1| 16.9 | 18.4 | 10.6 |     |
|                       | 6    | 42  | 26.6| 14.9| 19.5 | 22.1 | 12.6 |     |
|                       | 7    | 49  | 29.9| 17.8| 23.8 | 25.9 | 17.3 |     |
|                       | 8    | 56  | 28.9| 22.6| 28.5 | 25.1 | 21.7 |     |
|                       | 9    | 63  | 33.4| 27.6| 34.4 | 30.3 | 24.2 |     |
|                       | 10   | 70  | 30.6| 28.8| 29.3 | 29.9 | 18.2 |     |
|                       | 12   | 84  | 22.6| 22.7| 22.8 | 23.1 | 17.5 |     |
| 2010 (late season)    | 2    | 14  | 22.0| 21.6| 19.2 | 28.1 | 17.6 |     |
| (Sowing date August 2)| 3    | 22  | 12.9| 14.6| 14.4 | 17.3 | 14.4 |     |
|                       | 3    | 27  | 19.6| 18.1| 20.2 | 22.4 | 16.8 |     |
|                       | 5    | 36  | 15.9| 14.3| 12.1 | 17.3 | 14.3 |     |
|                       | 6    | 45  | 26.3| 22.7| 19.6 | 28.6 | 16.8 |     |
|                       | 7    | 52  | 27.5| 20.5| 16.4 | 20.8 | 16.3 |     |
|                       | 8    | 56  | 23.7| 29.7| 21.5 | 28.2 | 28.4 |     |
|                       | 11   | 77  | 24.8| 22.3| 22.3 | 30.8 | 23.6 |     |
|                       | 12   | 85  | 20.1| 20.1| 16.8 | 19.2 | 13.9 |     |
|                       | 12   | 89  | 22.6| 19.4| 18.7 | 22.4 | 22.1 |     |
| 2011 (early season)   | 2    | 14  | 11  | 15  | 14   | 10   | 12   |     |
| (Sowing date May 7    | 3    | 22  | 12  | 14  | 15   | 10   | 14   |     |
|                       | 5    | 36  | 20  | 25  | 21   | 20   | 22   |     |
|                       | 7    | 50  | 27  | 33  | 48   | 27   | 31   |     |
Notations: Contour bunds (CT); Infiltration pits (IP); Mulched plots (ML); Tied ridges (TR); and Conventional practice (CP) (Control), WAP, DAP are weeks and days after planting respectively.

|     |   8 |   9 |  10 |  11 |  12 |
|-----|-----|-----|-----|-----|-----|
|     |  56 |  64 |  70 |  78 |  85 |
|     |  28 |  31 |  12 |  13 |  10 |
|     |  37 |  40 |  11 |  14 |  12 |
|     |  32 |  40 |  15 |  13 |  10 |
|     |  26 |  35 |  10 |  10 |   8 |
|     |  32 |  38 |  12 |  13 |  10 |
Table 4. Mean Plant Height* at Maturity (m)

| Year           | CT  | IP  | ML  | TR  | CP  |
|---------------|-----|-----|-----|-----|-----|
| 2008 (late season) | 2.14c | 1.94b | 1.85a | 1.83a | 1.82a |
| 2009 (early season) | 1.43b | 1.95c | 1.68b | 2.01c | 1.01a |
| 2010 (late season) | 1.92c | 1.84a | 1.71a | 1.81a | 1.68a |
| 2011 (early season) | 1.93c | 1.64b | 1.52b | 2.12d | 1.46a |

*Values in the same row with the same letters are not significantly different (P>0.05)

[Contour bunds (CT); Infiltration pits (IP); Mulched plots (ML); Tied ridges (TR); and Conventional practice CP (Control)]

Table 5. Average Stem Girth (cm) at 5 and 10 WAP

| Year           | CT  | IP  | ML  | TR  | CP  |
|---------------|-----|-----|-----|-----|-----|
| 2008 (late season) | 1.46(3.61) | 1.93(2.44) | 1.77(2.38) | 2.24(3.01) | 1.76(2.38) |
| 2009 (early season) | 2.24(2.64) | 2.00(2.38) | 1.81(2.88) | 2.24(2.70) | 2.11(2.38) |
| 2010 (late season) | 2.14(2.87) | 1.94(2.51) | 1.74(2.72) | 2.18(3.18) | 1.75(2.28) |
| 2011 (early season) | 1.56(3.42) | 1.86(2.62) | 1.82(2.24) | 2.22(3.21) | 1.68(2.31) |

Values at 10 weeks after planting (WAP) in brackets.

of the seasons. The CT and TR plots gave the highest average number of leaves for the four seasons considered most especially at 5WAP. This may also be considered to be related to the average number of cobs and leaves produced by each treatment (Table 6) and the eventual grain yield of 2.71, 2.61 and 2.54 t/ha for TR, IP and CT respectively in the 2011 season (Table 7). The 2008 and 2009 seasons showed a marked relationship in the average number of leaves produced per plant in the IP, ML and the CP probably because these treatments could not retain water better than the CT and the TR plots.

Table 6. Average Number of Leaves and Cobs per Plant at 5 WAP

| Year           | CT  | IP  | ML  | TR  | CP  |
|---------------|-----|-----|-----|-----|-----|
| 2008 (late season) | 10 (2) | 8 (2) | 8 (2) | 11(2) | 8 (1) |
| 2009 (early season) | 11 (3) | 9 (2) | 9 (2) | 11(3) | 9 (2) |
| 2010 (late season) | 10 (2) | 9 (2) | 8 (2) | 12 (2) | 7 (1) |
| 2011 (early season) | 12 (3) | 9 (2) | 10 (2) | 13 (3) | 8 (1) |

Average number of cobs in brackets.

Table 7. Average Grain Yield in t ha⁻¹

| Year           | CT  | IP  | ML  | TR  | CP  |
|---------------|-----|-----|-----|-----|-----|
| 2008 (late season) | 2.08a | 0.96a | 1.16a | 2.15a | 0.88a |
| 2009 (early season) | 2.92d | 1.14b | 1.72b | 3.28c | 1.48b |
| 2010 (late season) | 2.23b | 1.05b | 2.22c | 2.13a | 1.24c |
| 2011 (early season) | 2.54c | 2.61c | 2.46d | 2.71b | 2.50d |

*Values in the same column with the same letters are not significantly different (P>0.05)

3.5 Yield parameters measurement
3.5.1 Average number of cobs per plant. The average number of cobs recorded in the various soil moisture conservation methods showed multiple cobs formation in both CT and TR in the 2009 early planting season and this may be attributed to better water retention and better recorded rainfall for the growing season. The 2011 early planting season also had multiple cob formation and better water
retention in the CT and TR compare to the CP of that same year. The CP showed an average of a cob per plant stand, maybe because very little amount of water was retained in the topsoil by this method.

3.5.2 Grain and dry matter yield at maturity. Yield measurements were recorded at harvest after drying on the field to level of water content not far from that obtained in commercial grain (10-15%) [40]. The above-ground shoot were also weighed and recorded for dry matter (biomass) yield. The noticeable differences in growth parameters which was as a result of the various treatments were also reflected in the yield components obtained from each treatment. The mean yield recorded from the individual treatments showed that CT gave the highest grain yield while the CP gave the lowest. Other treatments gave yield in the order of TR>IP>ML. Table 7 gave the average yield in t ha\(^{-1}\) for the respective soil moisture conservation methods. On the average, the CP in most cases gave the lowest yield both within the treatments and among the years because of unavailability of water most especially at the critical stages of plant development.

3.5.3 Hundred grain weight. The hundred grain weights were also recorded (Table 8). This showed variations in the seed quality produced by the various treatments and that which will be of good market value, more acceptability, and meet seed viability standards. The TR showed good seed quality in the 2008, 2010 and the 2011 planting season compared to the CP of the same years. Early stage of development and growth in TR and CT were without any form of water stress because of the water retention ability of the treatments.

3.6 Growth and grain yield with soil moisture replenishment. The four levels of soil moisture replenishment in 2011 showed different results in terms of VWC, growth/development and the yield parameters. Soil volumetric water content was monitored accordingly with the various levels of soil moisture replenishment. The 50, 25, 12.5 and 6.25 % level of replenishment translates to 40, 20, 10 and 5 mm of depth of supplementary runoff water added to the plots. At 5WAP, the VWC content of the soil at the levels of soil moisture augmentation is as shown in Fig. 2. The water retention ability of the various SWC methods differs even with the level of replenishment. The ML showed the best water retention at 5 WAP for the 2\(^{nd}\), 3\(^{rd}\) and 4\(^{th}\) levels of replenishment and this may be because the mulches provided a very low evaporative loss and a better infiltration rate. The least retention was observed in TR at the 5WAP because of the sandy nature of the soil. It was observed that compared with the CP; VWC of the soil varies greatly. The ML retained better moisture at the various levels of replenishment but this does not translate to grain and biomass yields at the end of the season because the ML treatment had the lowest yield. The fifth level of soil water replenishment also showed better VWC despite the fact that the least amount of water was added from the runoff as supplementary water to the crop. At 10 WAP, VWC retention follows the same trend with the ML plots retaining moisture better than the others (Table 9). The CT is similar in water retention to the TR but only that in the CT additional amount is trapped by the contours across the slope of each plot.

Yield for the year 2011 showed TR and CT with the highest grain yield of 3.21 and 3.02 t/ha respectively which occurred at the second level of soil moisture replenishment (Fig. 3). The third and fourth levels of replenishment also showed the same trend for TR and CT and in the decreasing order CP<IP<ML for the other treatments (Table 10). The CP consistently showed lower values of grain yield most especially at the fourth and fifth replenishment levels. This may be attributed to the fact that even at the lower levels of water replenishment, the condition of the top soil without any form of soil conservation could not retain much water for use by the plants.

The non-uniform distribution of rainfall in the entire growing season may be ameliorated by the in-situ runoff collection that can be reapplied to replenish and make moisture available for the crop. Also, moisture stress at critical stages of growth and development can be mitigated against with this replenishment or runoff water addition.

The TR and CT which gave the best grain yield also showed variations according to the levels of soil moisture replenishment. The fifth level gave 2.32 and 0.86 t/ha of grain yield for the CT and TR.
respectively in comparison with the CP of the same level which gave 0.52 t/ha grain yield. The yield variations for CT and TR at the level of soil moisture replenishment are as shown in Fig. 4. The TR and CT gave the best grain yield at 50 and 25% levels of soil moisture replenishment respectively while in the CP plot, yield decreases linearly as the level of replenishment decreases.

**Table 8. Average Hundred Grain Weight (g)**

| Soil moisture conservation methods | CT   | IP   | ML   | TR   | CP   |
|-----------------------------------|------|------|------|------|------|
| 2008                              | 2.22 | 1.49 | 2.01 | 2.15 | 2.03 |
| 2009                              | 1.78 | 0.82 | 1.81 | 1.86 | 1.85 |
| 2010                              | 1.92 | 0.94 | 1.96 | 2.23 | 2.14 |
| 2011                              | 1.42 | 0.75 | 1.54 | 2.87 | 1.98 |

*Values in the same row with the same letters are not significantly different (P>0.05)*

**Figure 2.** Soil VWC at 5WAP as Affected by the Conservation Methods and Level of Soil Moisture Replenishment.

**Table 9.** Soil VWC at 10 WAP (%) with the Level of Soil Moisture Replenishment

| Level of replenishment | Soil moisture conservation methods |
|------------------------|-----------------------------------|
|                        | CT  | CP | IP  | ML  | TR  |
| 1                      | 12  | 12 | 11  | 15  | 09  |
| 2                      | 09  | 13 | 18  | 13  | 10  |
| 3                      | 13  | 14 | 10  | 15  | 10  |
Figure 3. Grain Yield and Soil Moisture Conservation Methods at the 2nd Level of Moisture Replenishment. (722 mm of Recorded Rainfall Plus 40 mm Replenishment = 762 mm)

Table 10. Grain Yield for the 2011 Season

| Soil moisture replenishment levels | CT  | IP  | ML  | TR  | CP  |
|-----------------------------------|-----|-----|-----|-----|-----|
| 1 (rainfed)                       | 2.54b | 2.61d | 2.46c | 2.71e | 2.50d |
| 2 (50%)                           | 3.02d | 2.14c | 2.73d | 3.21d | 1.53c |
| 3 (25%)                           | 2.96d | 2.03b | 2.56d | 2.64c | 1.04b |
| 4 (12.5%)                         | 2.64c | 1.82a | 1.87a | 1.98b | 0.63a |
| 5 (6.25%)                         | 2.32a | 1.62a | 1.24b | 0.86a | 0.52a |

*Values in the same column with the same letters are not significantly different (P>0.05)


Figure 4. Average Grain Yield for TR and CT Compared with CP at the Five Levels of Soil Moisture Replenishment.

3.7 Crop yield and WUE

The grain and dry matter yield for the 2008-2011 season is as shown in Table 11. The results showed higher values of both biomass and grain yield for TR and CT treatments in the four seasons and all TR values were significantly higher than other treatments within the same year. The highest grain yield was recorded in 2009, which also had the highest seasonal ET. This is expected because more water was made available to the crops by the conservation method of TR. The average grain and biomass yield varies significantly within the years even for the same conservation practice (Table 12). The water use efficiency (WUE) is an indication of the amount of water required to produce the total yield (biomass and grains). The WUE varies within the treatments for the same year and also a significant variation occurs among the cropping seasons considered (Table 11).

| Year | Total annual rainfall (mm) | Measured rainfall for the season (mm) | Total seasonal ET (mm) | Average grain and dry matter yield (t/ha)* |
|------|---------------------------|--------------------------------------|-------------------------|------------------------------------------|
|      |                           |                                       |                         | CT | IP | MI | TR | CP |
| 2008 | 1457.20                   | 663.30                               | 286                     | 2.08 | 0.96 | 1.16 | 2.15 | 0.88 |
|      |                           |                                       |                         | (6.25) | (6.32) | (5.16) | (7.09) | (4.33) |
| 2009 | 1168.10                   | 865.70                               | 486                     | 2.92 | 1.14 | 1.72 | 3.28 | 1.48 |
|      |                           |                                       |                         | (7.20) | (7.32) | (8.10) | (9.33) | (4.76) |
| 2010 | 1320.40                   | 684.80                               | 315                     | 2.23 | 1.05 | 2.22 | 2.13 | 1.24 |
|      |                           |                                       |                         | (7.51) | (10.0) | (8.40) | (8.0) | (5.54) |
| 2011 | 1387.80                   | 722.20                               | 392                     | 2.54 | 2.61 | 2.46 | 2.71 | 2.50 |
|      |                           |                                       |                         | (11.94) | (9.25) | (11.22) | (10.61) | (7.60) |

*Dry matter yields in brackets
In the 2011 with some levels of soil moisture replenishment after soil moisture depletion, there was a significant difference in grain and biomass yield when the values were compared within the conservation practices. The 50% level of replenishment gave the highest yield with the TR treatment and this was closely followed by the CT and ML treatments of the same level of replenishment (Table 12). The CP treatment performed so poorly at all levels apparently because the level of soil moisture replenishment could not meet the water demand of the crop whenever there was water depletion in the root zone. These results showed that, soil moisture replenishment to the level of about 50% was good enough to meet the crop requirements for moisture abstraction. The 25% level of replenishments also gave reasonable yield results over the 12.5 and 6.25% levels. Water use efficiency was the best in TR for the 50% replenishment and in all cases the CP gave a comparatively low WUE. This is more pronounced in the last level of replenishment (Table 13).

### Table 12. Total Water Use for the Year 2008-2011 Seasons

| Year | Treatment | Total Rainfall (mm) | Total Yield (Grain and biomass) (t ha⁻¹) | WUE (kg m⁻³) | R² value |
|------|-----------|---------------------|-----------------------------------------|-------------|----------|
| 2008 | CT        | 666.30              | 8.33                                    | 2.91        |          |
|      | IP        | 7.28                | 2.55                                    |             |          |
|      | ML        | 6.32                | 2.21                                    |             |          |
|      | TR        | 9.24                | 3.23                                    |             |          |
|      | CP        | 5.21                | 1.82                                    |             |          |
| 2009 | CT        | 865.70              | 10.12                                   | 2.08        |          |
|      | IP        | 8.46                | 1.74                                    |             |          |
|      | ML        | 9.82                | 2.02                                    |             |          |
|      | TR        | 12.61               | 2.60                                    |             |          |
|      | CP        | 6.24                | 1.28                                    |             |          |
| 2010 | CT        | 684.80              | 9.74                                    | 3.09        |          |
|      | IP        | 11.05               | 3.51                                    |             |          |
|      | ML        | 10.62               | 3.37                                    |             |          |
|      | TR        | 10.13               | 3.22                                    |             |          |
|      | CP        | 6.78                | 2.15                                    |             |          |
| 2011 | CT        | 722.20              | 14.48                                   | 3.70        |          |
|      | IP        | 11.86               | 3.03                                    |             |          |
|      | ML        | 13.68               | 3.49                                    |             |          |
|      | TR        | 13.32               | 3.40                                    |             |          |
|      | CP        | 10.10               | 2.58                                    |             |          |

### Table 13. Grain and Dry Matter Yield for the 2011 Season with the Levels of Soil Moisture Replenishment

| Soil moisture replenishment levels | Total water, (mm) | Seasonal ET (mm) | Grain and dry matter yield t ha⁻¹ |
|-----------------------------------|-------------------|------------------|---------------------------------|
| 1 (rainfed)                       | 722.20            | 392              | CT 2.54 (11.94) IP 2.61 (9.25) ML 2.46 (11.22) TR 2.71 (10.61) CP 2.50 (7.60) |
| 2 (50%)                           | 762.20            | 392              | CT 3.02 (10.60) IP 2.14 (9.65) ML 2.73 (7.34) TR 3.21 (12.34) CP 1.53 (7.85) |
|   | 3 (25%) | 4 (12.5%) | 5 (6.25%) |
|---|---------|----------|----------|
|   | 742.20  | 732.20  | 727.20  |
|   | 392     | 392     | 392     |
|   | 2.96(8.94) | 2.64(8.26) | 2.32(7.15) |
|   | 2.03(9.65) | 1.82(9.40) | 1.62(9.31) |
|   | 2.56(7.25) | 1.87(6.82) | 1.24(6.81) |
|   | 1.04(7.34) | 1.98(9.14) | 0.86(8.62) |
|   | 2.64(10.52) | 1.98(9.14) | 0.86(8.62) |

*Dry matter yield in brackets*
Table 14. Total Water Use for the 2011 Season with the Levels of Soil Moisture Replenishment

| Soil moisture replenishment levels | Treatment | Total water use (mm) | Total yield - Grain and biomass (t ha⁻¹) | WUE (kg m⁻³) |
|-----------------------------------|-----------|----------------------|------------------------------------------|-------------|
| 1                                 | CT        | 722.20               | 14.48                                    | 3.69        |
|                                  | IP        |                      | 11.86                                    | 3.03        |
|                                  | ML        |                      | 13.68                                    | 3.49        |
|                                  | TR        |                      | 13.32                                    | 3.40        |
|                                  | CP        |                      | 10.1                                     | 2.58        |
| 2 (50%)                          | CT        | 762.20               | 13.62                                    | 3.38        |
|                                  | IP        |                      | 11.79                                    | 3.01        |
|                                  | ML        |                      | 10.07                                    | 2.57        |
|                                  | TR        |                      | 15.55                                    | 3.97        |
|                                  | CP        |                      | 9.38                                     | 2.39        |
| 3 (25%)                          | CT        | 742.20               | 11.90                                    | 3.04        |
|                                  | IP        |                      | 11.68                                    | 2.98        |
|                                  | ML        |                      | 9.81                                     | 2.50        |
|                                  | TR        |                      | 13.16                                    | 3.36        |
|                                  | CP        |                      | 8.38                                     | 2.14        |
| 4 (12.5%)                        | CT        | 732.20               | 10.9                                     | 2.78        |
|                                  | IP        |                      | 11.22                                    | 2.86        |
|                                  | ML        |                      | 8.69                                     | 2.22        |
|                                  | TR        |                      | 11.12                                    | 2.84        |
|                                  | CP        |                      | 7.65                                     | 1.95        |
| 5 (6.25%)                        | CT        | 727.20               | 9.47                                     | 2.42        |
|                                  | IP        |                      | 10.93                                    | 2.79        |
|                                  | ML        |                      | 8.05                                     | 2.05        |
|                                  | TR        |                      | 9.48                                     | 2.42        |
|                                  | CP        |                      | 6.76                                     | 1.72        |

4. Conclusions

The SWC practices introduced to the plots confirmed that substantial yield improvement is obtainable, although these values were within the range reported in literature. The TR and CT gave better yields when compared to the ML and IP of the same year. The 50 and 25% soil moisture replenishment also gave better yield when compared with other levels of replenishments. The biomass yield for the 2008-2010 planting season had higher values in TR, IP and CT compared to the CP. Soil moisture retention ability of the treated plots revealed that the highest soil moisture retention values were obtained in the TR, while slightly different values were obtained in the CT of the same year in the weeks after planting (WAP). These showed that the various SWC methods retained water differently. In the 2011 experiment with five levels of soil moisture replenishment after depletion by 50% of FC, TR also gave the highest moisture retention values followed by the IP which gave a slightly different value. In the growth parameters, plant height varied between 1.01 and 2.14 m at harvest. The CP had the least while
the CT had the highest in 2008 and 2010. Mean variation in plant height at maturity showed TR and CT to be of better height than the CP of the same year. In the mean stem girth (diameter) at 5 and 10 WAP; higher values were measured in the order CT > IP > TR in the season.

The yield and WUE showed that the WUE varies within the treatments for the same year and also a significant variation (P≤0.05) occurred among the cropping seasons considered. In the 2011, the 50% level of replenishment gave the highest yield in the TR treatment followed by the CT and ML treatments of the same level of replenishment. The CP treatment performed poorly at all levels, an indication that enough water was not available for the plants. Water use efficiency was the best in TR for the 50% replenishment and in all cases the CP gave a comparatively low WUE. This showed that the various conservation practices enhances better infiltration and soil moisture storage to a certain degree when compared with the traditional practice.

In the overall outcome of this study; on-farm RWH, soil and water conservation (SWC) practices and field management conditions was able to contribute significantly to improved and higher yield for the maize cropping season in the study area. The study also showed that there are variations in the water-use efficiency according to the field management conditions and conservation practices. The study was able to generate much needed data to bridge the gap between on-farm RWH, soil and water conservation (SWC) practices and field management conditions for the maize cropping season. This study was also able to quantify the potentials of on-farm RWH technology and SWC practices with or without supplementary irrigation for maize production.

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