EFFECT OF RAIN WATER HARVESTING AND DRIP IRRIGATION ON CROP PERFORMANCE IN AN ARID AND SEMI-ARID ENVIRONMENT

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Abstract

Rainwater harvesting and drip irrigation are possible interventions to enhance crop performance in Arid and Semi-Arid Lands (ASAL). Work was undertaken to evaluate the feasibility of rainwater harvesting for bean production under an ASAL environment in Kaiti Watershed, Makueni District, Kenya. Treatments comprised two rainwater harvesting methods, Zai pits and contour ridges; bucket-kit drip irrigation and a control. No intervention was made to enhance water availability in the crop root zone in the control. The experiment was arranged in a Randomized Complete Block Design with three replicates. Each of the 12 experimental plots was planted with beans (*Phaseolus vulgaris* L.), variety GLP 2. Soil moisture content and pan evaporation were measured daily for 100 days and runoff after every rainfall event. Crop height was measured once a week and grain and biomass yield were determined at the end of the growing season. Soil moisture content and crop performance were significantly influenced by drip irrigation but not by rainwater harvesting. In drip irrigated plots, grain and biomass yield, were 4 tonnes ha^{-1} and 9 tonnes ha^{-1} respectively compared to 3.5 tonnes ha^{-1} and 7.5 tonnes ha^{-1} respectively, in the control plots. Drip irrigation effectively maintained adequate soil moisture resulting in better crop performance while rain water harvesting methods failed to significantly enhance soil moisture content and crop performance. This study indicated that rainwater harvesting makes a difference in runoff when the 14 Day Antecedent Precipitation (14DAP) exceeds 80 mm. However, the grain yield obtained in all the plots was higher than the national average of 0.36 tonnes Ha^{-1}. It is recommended that further research be done under different rainfall conditions to confirm the conditions under which the benefits of rainwater harvesting using contour ridges and zai pits can be realized in the enhancement of crop performance in ASAL conditions.

Key words: ASAL, soil moisture content, *Phaseolus vulgaris* L, Zai pits, contour ridges drip irrigation, rainwater harvesting

1.0 Introduction

Water that is held in the spaces between soil particles is referred to as soil moisture. Surface soil moisture is the water stored in the upper 10 cm of soil. The root zone depth, depending on the crop varies between 60 cm for shallow rooted crops like cabbage to about 200 cm for deep rooted crops such as citrus (Michael, 1978). Compared to other components of the hydrologic cycle, the volume of soil moisture is small; nonetheless, it is of fundamental importance to many hydrological, biological and biogeochemical processes. Soil moisture information is valuable to those who are concerned with weather and climate, runoff potential and flood control, soil erosion and slope failure, reservoir management, geotechnical engineering, and water quality.

Arid and Semi Arid Lands (ASAL) are those areas characterized by low, poorly distributed, and highly variable rainfall within 100-600 mm per year (Mugwe et al, 1999). The ASAL in Kenya covers over 80 % of the country. These vast lands are generally poor and experience food scarcity. Accurate knowledge of soil water content, in ASAL areas is essential for proper soil water management, irrigation scheduling and crop production. However, the data necessary for sound agricultural water management is often scarce.

Studies have shown that agriculture in the ASALs of East Africa is mostly rain-fed (Hatibu and Mahoo, 2000; Critchley, *et al.* 1999). Therefore, moisture stress is a major constraint against food production in these areas. Demand for water use in agriculture will continue to increase as a result of growing population and economic growth (Rosegrant, 2009).This is a threat to food security. To guarantee food security, sound Agricultural Water Management (AWM) is necessary. AWM includes all deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes (Mati, 2007). AWM include practices such as irrigation (supplemental or full), drainage, soil and water conservation, rainwater harvesting, soil fertility management, conservation agriculture and wastewater reuse among others.
Sound agricultural management should ensure that available rainwater becomes useful to crops and that it is not used for negative impacts such as soil erosion. Wei *et al.* (2007) showed that surface runoff depends on the antecedent moisture conditions, and that when it rains during wet conditions, much of the rainwater is likely to be lost as runoff. Soil and water conservation with water harvesting, is one of the techniques for supporting rain-fed agriculture in the ASAL (Hai, 1998; Mati, 2006), where bean crop failure is observed during 3 out of every 10 seasons (Jaetzold (2007). On-farm rainwater harvesting using structures such as pits, bunds, basins and contour ridges preserve soil moisture and result in improved crop yields (Kaluli *et al.,* 2005; Gathenya and Kaluli, 2004). Zai pits, usually with a diameter of 0.3-0.6 m and 0.3 m deep, are used to harvest rain water at farm level. Manure may be put into the pits to improve soil fertility. Retaining the water in a pit prevents it from running off the farm and makes water available for crops. Another way of making water available for crop production is through the use of contour ridges and trenches. Ridging is the construction of furrows along a contour at a spacing of 1-2 m (Mati, 2007). In East and Southern Africa ridging is done for high value crops such as potatoes, groundnuts and

maize. Ridging and pits retard surface runoff, improve infiltration, and reduce soil erosion.

This project was conducted in Kaiti watershed which receives between 300 to 500 mm of rainfall annually (Nderitu, 2006). Dry spells of 2 weeks to 1 month during the growing season are a common feature in this area. Furthermore, soil erosion and degradation of organic matter, soil physical characteristics and soil fertility in Kaiti watershed make crops susceptible to water deficits. Information on soil water availability and the relationships between crop production and crop water use during the growing season is needed to assess crop water requirements and make good schedules for irrigation (Michael, 1978). This knowledge can be used to improve water use efficiencies and increase returns to the producer. Such information can also help farmers and the government to make better plans for development. Using the common bean (*Phaseolus vulgaris* L.), as the test crop, the effect of on-farm rain water harvesting on soil moisture and crop yield in the ASAL environment of Kaiti watershed was investigated, with the objective of providing information on the most suitable rainwater management technologies for arid

2.0 Materials and methods

2.1 Location of the study site

The research site, Kaiti watershed (1°44'1.5"S to 1°47'19.3"S; 37°13'13.4"E to 37°41'25.2"E), is located within the greater Makueni District, which borders Kajiado District to the west, Taita Taveta to the southeast, Kitui to the east and Machakos District to the North (Figure 1). It is typically ASAL with minimum monthly mean temperature of 10°C in July and a maximum of about 30°C in February. The rainfall pattern is bimodal, but generally scarce, with significant differences in distribution during different years. Average annual rainfall ranges from slightly over 1000 mm in the higher rainfall areas to less than 500 mm in the low lying south and southeastern parts of the district (Gichuki, 2000). The dry season falls between the months of January and February and between August and September. The average slope is 15-30% and the soil is deep sandy clay loam.

2.2 Experimental design

The study was carried out for 100 days from October 1, 2005 to January 8, 2006. Treatments comprised two rainwater harvesting methods, Zai pits and contour ridges, bucket-kit drip irrigation and a control. The Zai pits had a diameter of 30 cm and a depth of 30 cm. They were dug at a spacing of 90 cm between rows and 60 cm within the row. The contour ridges were 25 cm high and they were constructed at a spacing of 100 cm. The bucket-kit drip irrigation was set up at 1.0 m high on a wooden stand placed at the highest point of the plot. The water was filtered to remove sediments before being placed in the bucket to prevent clogging of the drip emitters. In the control no intervention was applied to enhance water availability.

The treatments were randomly allocated to experimental plots that were 3 m wide, along the contour, and 10 m long. The experiment was arranged in a Randomized

Complete Block Design (RCBD) with three replicates (Figure 2). To reduce interference between plots, galvanized iron sheets were placed around individual plots and placed at 30 cm below the ground and extended 30 cm above the ground. A 2 m buffer zone was also created between blocks. Each plot was planted with a bean crop (Phaseolus vulgaris L.), variety GLP 2 popularly known as "nyayo". In each treatment the beans were spaced at 15 cm to give a plant population of 17 per m2. Farm yard manure was applied at the rate of 10 ton ha-1 and Diammonium phosphate (DAP) fertilizer at 200 kg ha-1.

2.3 Land preparation

Land preparation, which involved digging using a hoe followed by harrowing, was carried out in late September and early October, 2005, before the onset of the rains. The land was then graded to achieve uniform slope within each block.

2.4 Drip irrigation and runoff measurement

Drip irrigation is a method of watering plants through devises called emitters (Figure 3). Drops of water come out one at a time to wet the soil around the roots of the plant. The "bucket drip kit" used in this study is a simple drip system commonly used by farmers in home gardens. It is made up of a bucket, a filter, connectors and a drip tape. Some 4 mm of water was applied daily through drip irrigation from November 20, 2005 to December 13, 2005. By this time the crop had matured to the point that it would not be affected by lack of irrigation water. For all treatments, a 50 mm PVC pipe was fixed at the outfall of each plot and directed into a 20 litre plastic container. The amount of runoff collected in the containers was measured at the end of each rainfall event.

2.5 Measurement of rainfall, evaporation and soil moisture

Soil moisture content and pan evaporation were measured daily during the study period with the help of a tensiometer placed at a depth of 15 cm, and Class A Evaporation pan, respectively. A rain gauge was used to measure daily rainfall.

2.6 Measurement of crop performance

The crop data collected included crop height, measured once a week; and grain and biomass yield for each treatment measured at the end of the experiment. Biomass was measured by uprooting randomly selected mature plants and weighing them. The beans were then threshed and the grain separated from the straws. Further weighing was then done. This gave the weight of grain as well as the weight of total biomass. At least twelve plants were sampled from every plot. To ease identification of the sampled plants the selected plants were tagged.

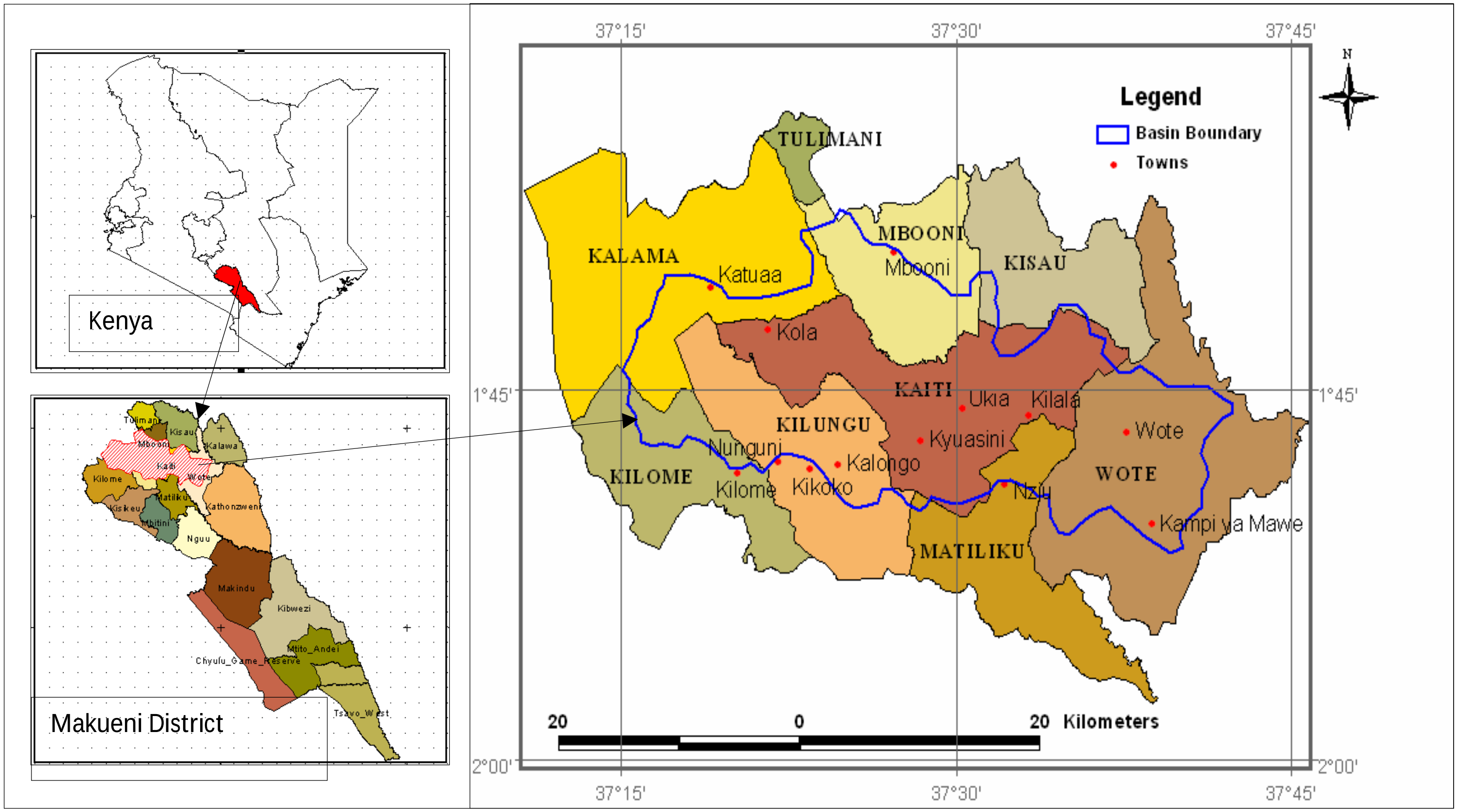

Figure 1: Location map of Kaiti watershed
Source: Nderitu, 2006

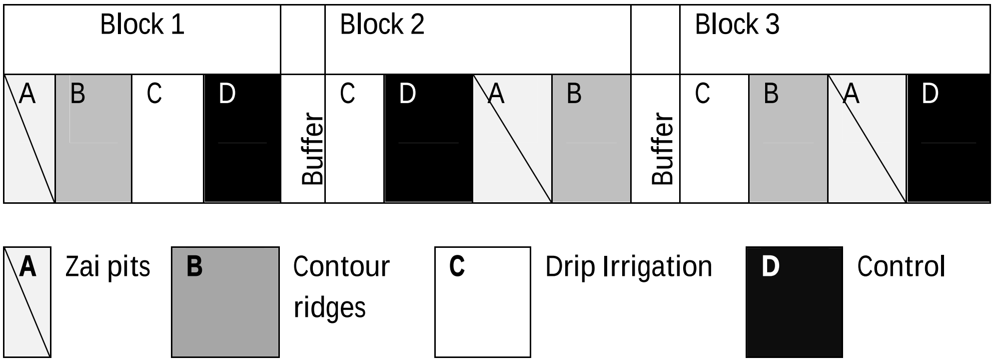

Figure 2: A sketch of experimental layout

Figure 3: Drip irrigation and use of tensiometers for soil moisture monitoring Statistical analysis

2.7 Statistical analysis

The Statistical Package for the Social Sciences (SPSS) was used for the statistical analysis on mean soil moisture content, mean crop height, and bean biomass yield. Analysis of variance (ANOVA) was chosen to analyze the data. The model for each analysis included the treatments; drip irrigation, ridging, zai pits and the control. The hypothesis of normal distribution of the residuals was verified.

3.0 Results and discussion

During the data collection period, 171 mm of rainfall occurred and was spread over the 100 days. During this period there were 24 wet days. For most of December 2005, the weather was dry and pan evaporation varied between 3 and 7 mm/day. The total pan evaporation for the study period was 359 mm, which translated to a daily average rate of about 3.6 mm. The highest daily rate of evaporation was 7.8 mm which was recorded on 17th January 2006. The lowest evaporation rate of about 2 mm/day was recorded in early November 2005 (Figure 4).

3.1 Effect of rainfall and evaporation on soil moisture

To evaluate the effect of rainfall and evaporation on soil moisture only the data for the control treatment was considered. Soil moisture content was highest between November 24, 2005 and December 14, 2005. This was the period with the most rainfall, when the weather was cooler, tending to reduce the rate of evaporation.

Most of December was dry and pan evaporation increased from 2.5 mm/day to about 7.0 mm/day, causing soil moisture content to decrease from about 14% to about 2% (Figure 4 and Figure 5). The rainfall received over a 14 day period, prior to a certain date is referred to as the 14 Day Antecedent Precipitation (14DAP). There was a strong linear relationship between the 14DAP and soil moisture content, suggesting that rainfall is the main factor affecting soil moisture content in this farm (Figure 6). Peaks of the 14DAP corresponded to soil moisture content peaks for different treatments (Figure 7).

3.2 Effect of rainwater harvesting and drip irrigation on soil moisture and crop performance

Zai pits and contour ridges did not significantly increase soil moisture when compared to the control. The pits and contour ridges failed to collect and store rain water and provide adequate moisture to crops even after the rain had stopped. Because rainfall was insufficient during most of the study period, there was hardly any surface runoff even from the control and drip irrigated plots. Soil moisture in drip irrigated plots was significantly higher than in the control plots, even after irrigation was discontinued (Figure 7).

The wettest period of the growing season was the last week of November 2007. After the rainfall event of November 27, when the 14DAP was about 80 mm, the control and drip irrigated plots yielded surface runoff of 2.5 – 2.6 mm. However, plots under Zai pits and contour ridges had less surface runoff of 0.8-0.9 mm. This suggests that a minimum 14DAP of 80 mm is required for runoff to be produced. However, there is need for further research to confirm the conditions under which rainwater harvesting would be effective in preventing runoff and enhancing root zone soil moisture. Crop performance was assessed in terms of crop height, biomass yield, and bean grain yield. Rainwater harvesting did not influence crop development in terms crop height (Figure 8). This is could have been because the rainfall received during the vegetative stage of plant growth was just enough for the purposes of plant growth. By end of November 2005, the bean crop had reached maximum height. The fastest growth occurred during the second month after planting.

The bean crop was harvested after 100 days and the highest biomass yield was 9 tonnes ha-1 realized in drip irrigated plots. However, biomass yield for drip irrigated plots was not different from the control treatment. Biomass yield from zai pits and contour ridges was significantly lower than the yield from drip irrigated plots at 5% level of signicance (Figure 9). Although Mati (2006) found that contour ridges increased the yield of maize in semi–arid climate, in this study, beans planted in contour ridges did not perform as well. This was contrary to expectations. Bean yields were higher than the national average of 0.36 tonnes ha-1 (Ministry of Agriculture, 2009) and higher than the average bean yield for Makueni District (0.4 tonnes ha-1) (Jaetzold, 2007) for all the treatments. Drip irrigated plots had the highest average bean grain yield of 4.0 Ton ha-1.

Reasons for lack of rainwater harvesting impact on bean yield are unknown. The fact that there was minimal runoff suggests that most of the rainfall went into the soil uniformly in all the plots, and hence the reason crop yield from plots that were not irrigated was nearly the same, irrespective of rainwater harvesting.

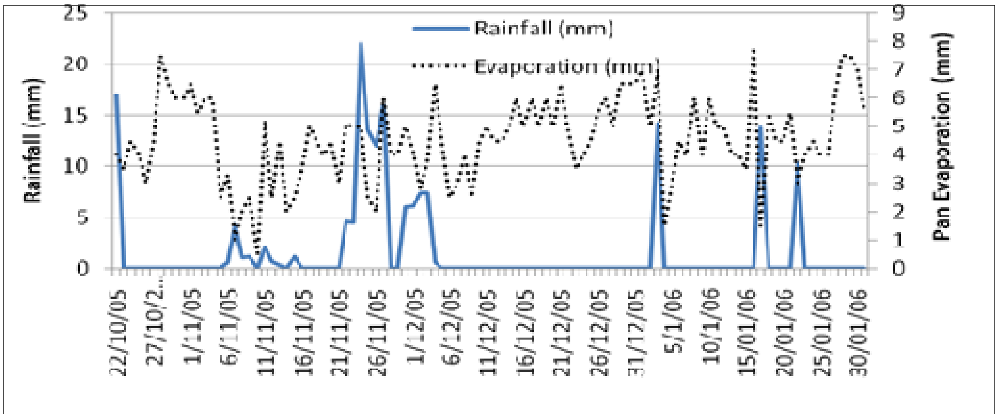

Figure 4: Temporal variation of rainfall and pan evaporation data during the study period

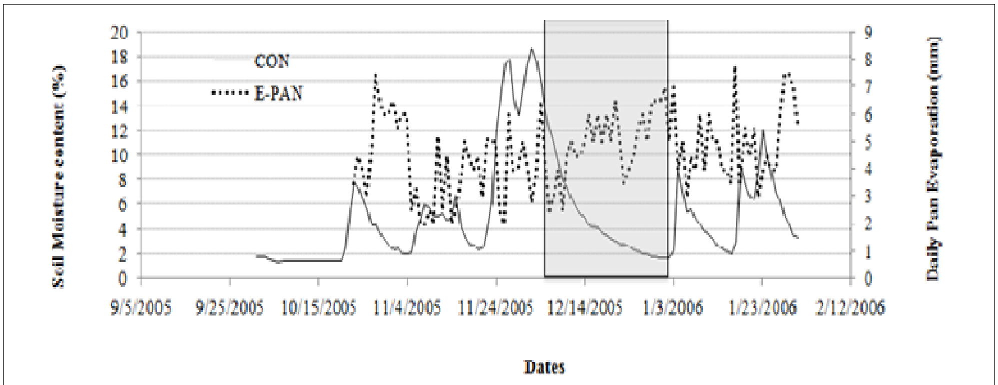

Figure 5: Soil moisture and evaporation data for the experimental period

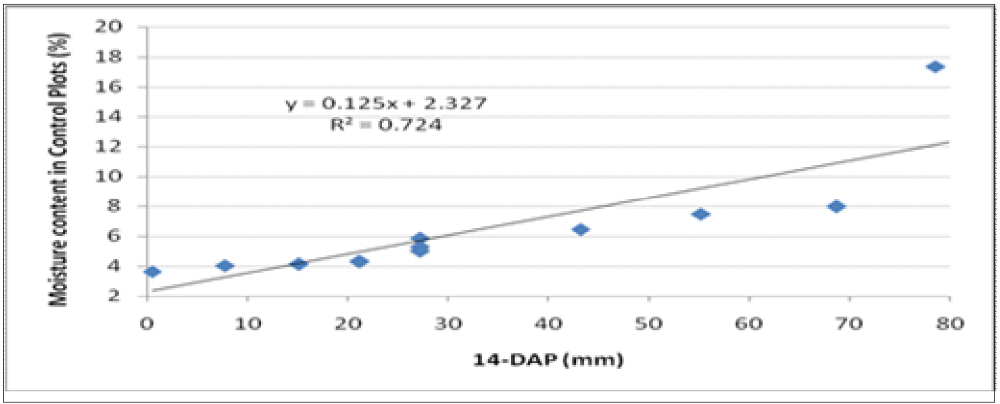

Figure 6: Soil moisture and evaporation data for the study period

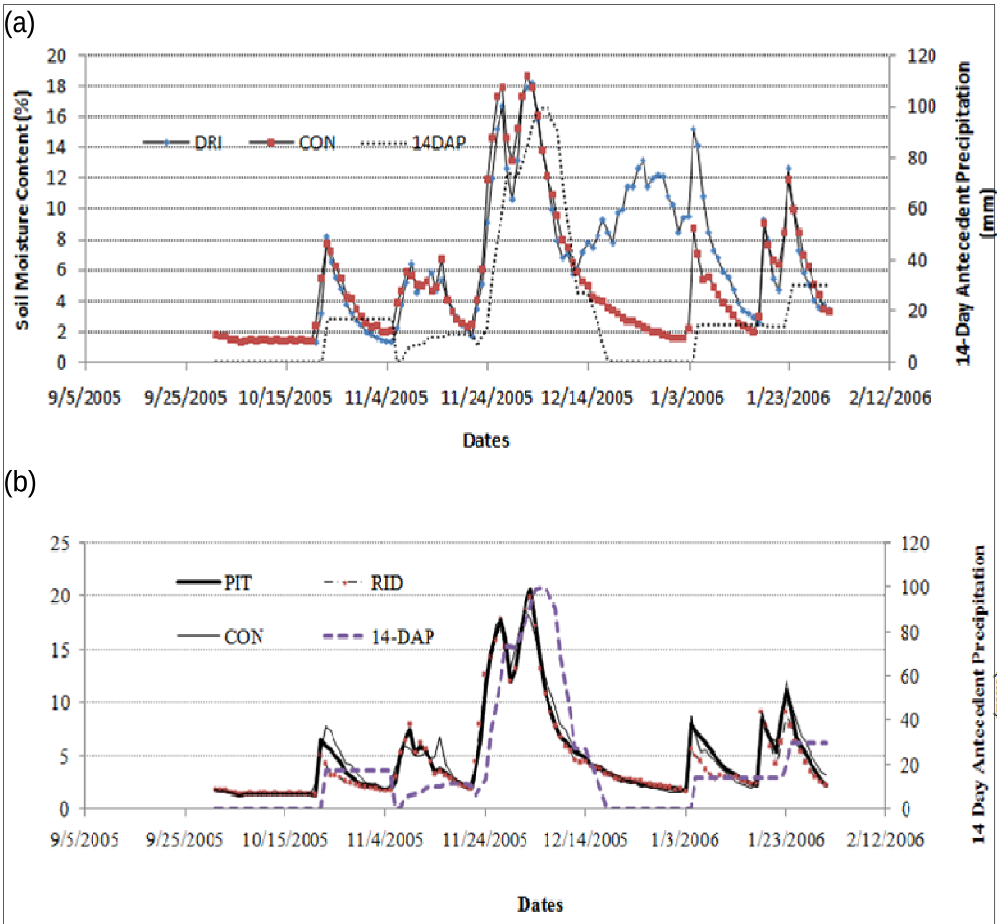

Figure 7(a-b): Effect of rainfall on Soil moisture content: (a) Control versus Drip; (b) Control versus Zai Pits and Contour ridges

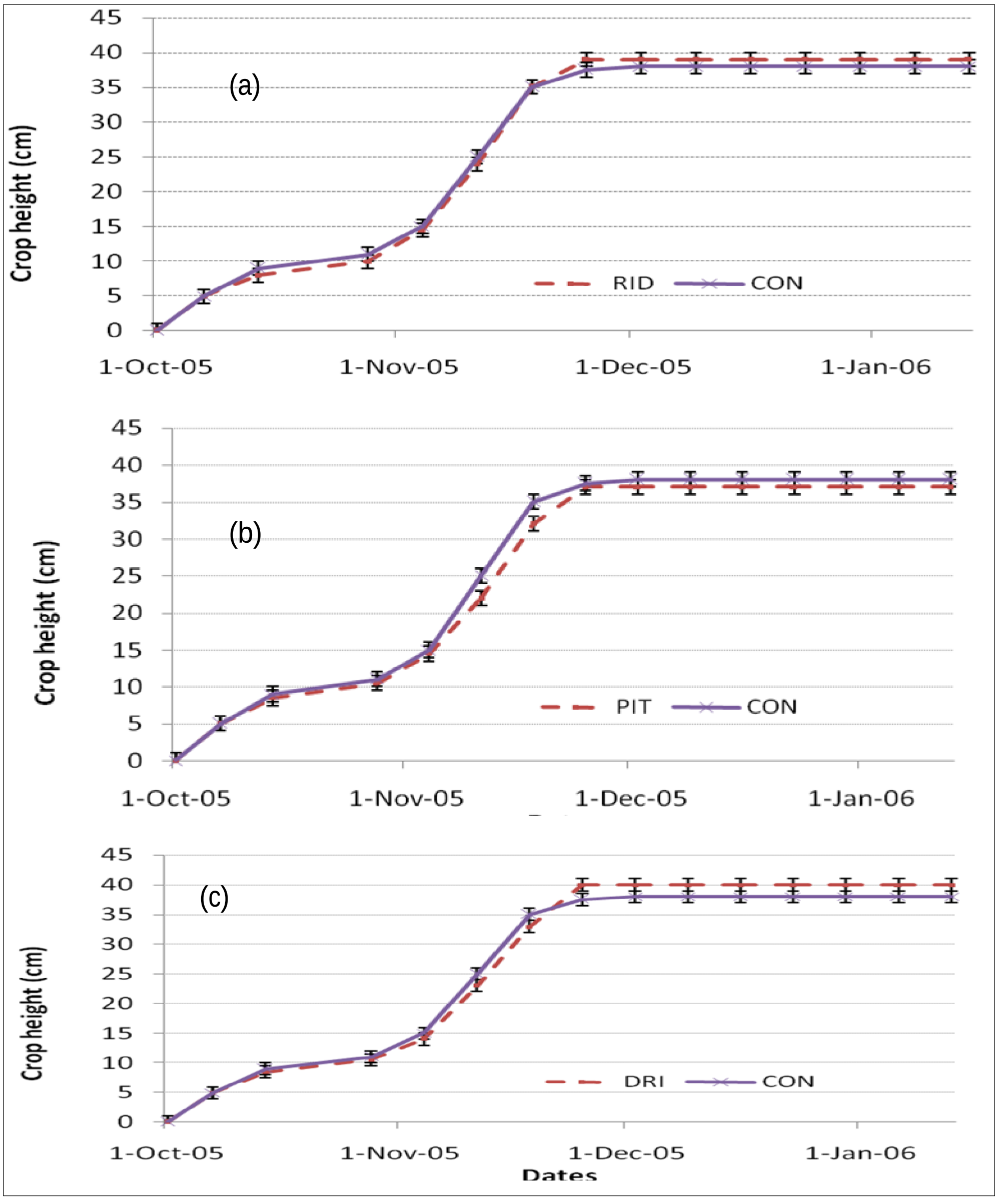

Figure 8 (a-c): Effect of water harvesting and drip irrigation on crop height: (a) Contour ridges versus control; (b) Zai pits versus control and (c) Drip irrigation versus control

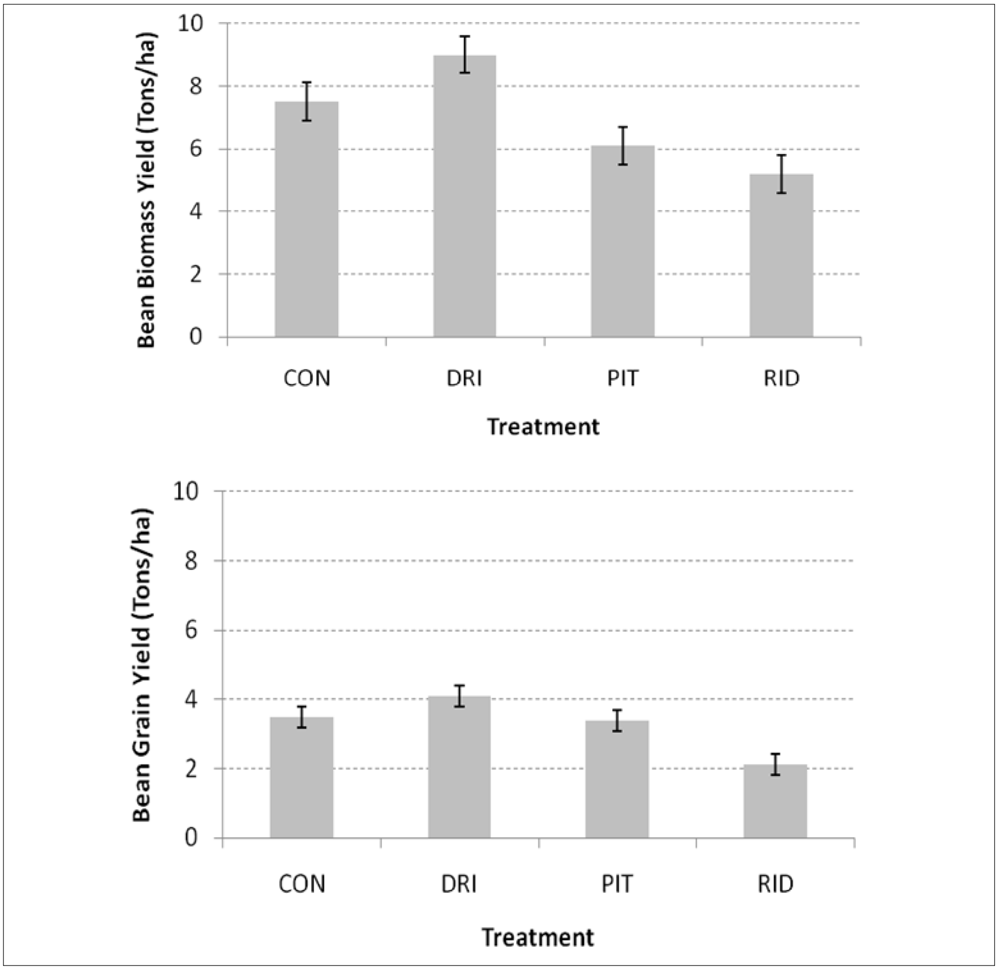

Figure 9: Bean grain and biomass yield

4.0 Conclusions and recommendations

The strong linear relationship between the 14 Day Antecedent Precipitation (14DAP) and soil moisture content indicates that rainfall is the main factor affecting soil moisture content and crop performance. Under the soil and crop conditions used in this study, a minimum 14DAP of 80 mm is necessary for surface runoff to be produced, and therefore for the impact of rainwater harvesting on soil moisture to be observed. Further research, under various rainfall and soil conditions should be undertaken to confirm the conditions under which the benefits of rainwater harvesting using contour ridges and zai pits can be realized in the enhancement of crop performance in ASAL conditions.

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