To retain or to drain water in agricultural fields of semi-arid regions using contour ridges

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Abstract

Water is a major limiting factor to crop production in many semi-arid conditions, yet a substantial amount of it is lost from agricultural fields and adjacent land through runoff. Several innovations have been developed in the past to improve water availability to field crops by harnessing the excess runoff. The contribution of graded contour ridges, structures developed to control rill and gully erosion, to harvesting excess runoff for the benefit of crops however still remains unquantified. Retaining the water in the contour ridge provides time for infiltration to take place which may result in field crops benefiting. Furthermore it remains unknown whether ungraded or dead level contours retain and harvest more water than graded ones. This paper presents results of a study being carried out in Zhulube catchment of Insiza District of Zimbabwe. Soil moisture data across plots with dead level contour ridges are compared to those across plots of graded contour ridges. The results, from this ongoing study, appear to suggest that water harvesting in the field through dead level contour ridges is beneficial.

Key words: semi-arid, contour ridges, soil moisture, excess runoff, water harvesting.

Introduction

Contour ridges are often mentioned as one of the methods of rainwater harvesting (Al Ali et al, 2008; Nasri et al 2004; Falkenmark eta al 2001). However there is no empirical evidence presented on whether these structures really conserve water let alone how they conserve it.

The development of contour ridges in Zimbabwe was necessitated by the problem of soil erosion and the ridges were thus designed to drain away the water. Thus the designs were geared to safely dispose of excess runoff and prevent rill and gulley erosion. With more frequent droughts in recent years an interest in the use of contour ridges for water conservation has developed. This has led to a new design in which the contour ridge is constructed at a zero gradient and is often called a dead level contour. This design has been implemented by nongovernmental organizations often on a massive scale. The organizations implementing this design have claimed success of the strategy arguing the massive adoption by the farmers is an indication of the effectiveness of the strategy. However some researchers have suggested that the adoption alone does not imply effectiveness of a strategy as the farmers may have been attracted by other factors. The organizations often give away equipment for use in making the ridges e.g. picks and shovels which eventually becomes part of the farmers' household equipment. This calls for the search of evidence on improvement in water availability as a result of the contour ridges.

An attempt to provide evidence was made by Mugabe (2004) who studied contour ridges with infiltration pits and showed that incorporation of the infiltration pit resulted in improved soil moisture. A similar study was carried out by Mupangwa et al, (2006) who arrived at the conclusion that there was no significant improvement in soil moisture except for high rainfall events as high as 40mm/day. However both studies did not make a comparison between the standard design that was developed for soil erosion control and the improved design that retains water in the ridge. Besides the conclusion arrived at by the two studies are not entirely in agreement therefore calling for further studies to provide more empirical evidence.

Materials and Methods

This study was carried out to compare the soil moisture availability in a plot with dead level contours against one with the standard graded contour. In order to achieve this objective experimental work is being carried out in Zhulube Catchment.

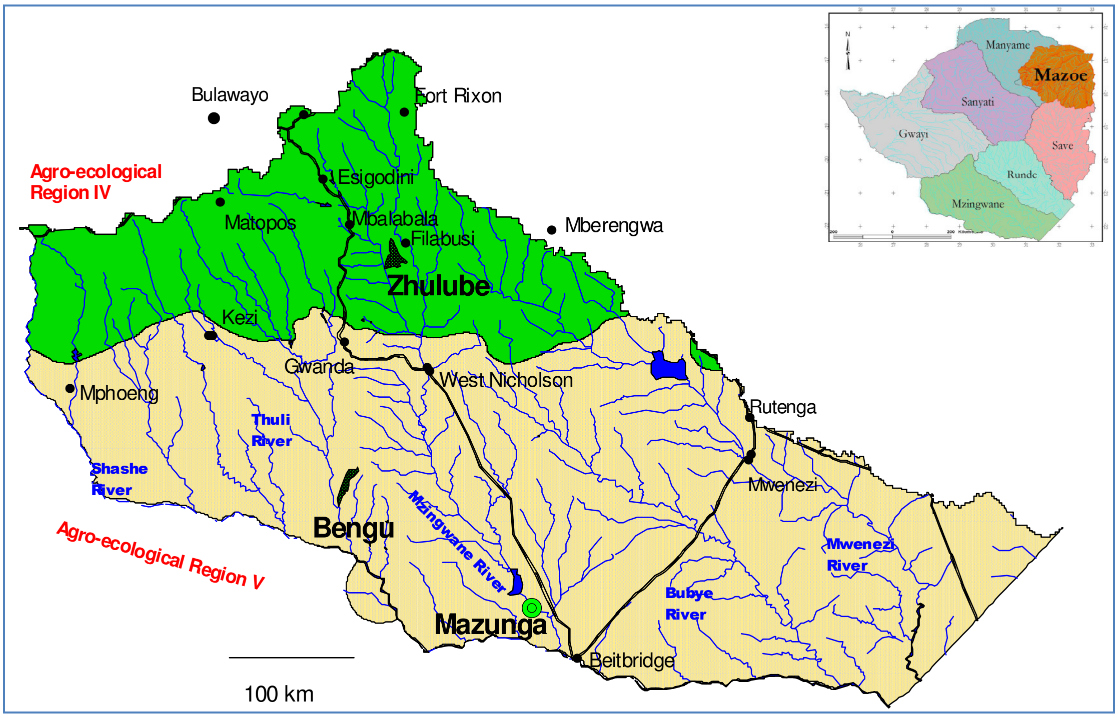

Figure 1: Location of Zhulube Catchment in Zimbabwe

Zhulube Catchment is a sub catchment of Mzingwane Catchment that lies in the south west part of Zimbabwe and is part of the Limpopo River Basin (Figure 1). It is located in a communal area of Insiza District in Matebeleland South province of Zimbabwe. The catchment is mountainous with an area of 21 km^2 upstream of an important small dam supporting a 40 ha irrigation scheme. Land use is dominated by grazing with rain fed cultivation taking up 15% of the land (Dondofema, 2007). Gold mining and panning is practiced in part of the upstream catchment.

Zhulube Catchment receives low annual rainfall averaging 540mm. Frequent crop failure discourages farmers from practicing rain fed farming (Mwamba, 2007). All these catchment characteristics lead to high runoff and sediment generation. The Zhulube dam at the downstream end of the catchment is threatened with sedimentation. Already an old dam immediately upstream of it is full of sediments. Adoption of contour ridges in such a catchment could prove to be a very important water conservation strategy as it has the potential to protect the dam. However its sustainability depends on the rain fed farmers deriving benefit from the practice. Thus the catchment was considered ideal for research on the potential of water conservation benefits derived from contour ridges.

Experimental Arrangement

Five farmers were selected to provide fields for experimental work based on soil type, slope and willingness of farmers to participate. It is desirable that the field have a uniform slope, soil type and underlying geology to enable differences observed in soil moisture to be attributable to effect of contour ridges. This condition is difficult to meet in most farmers' fields within Zhulube catchment owing largely to the adulating topography of the area. The best possible sections of the field from those farmers who were willing to participate were however selected.

Two basic designs were implemented in each plot. The first design prevents runoff water from leaving the field through a contour ridge constructed at a zero gradient. The second drains runoff water away from the field through contour ridges constructed at graded slope. The first type of contour ridge is thus called dead level (meaning zero slope) contour. The second type is a graded (at a slope) contour. In each farmer's field there are plots containing these two designs. In addition there is also a third plot were there are no contours. Figure 2 illustrates the arrangement of the three experimental plots in a farmer's field.

Proposed field experimental plot arrangement

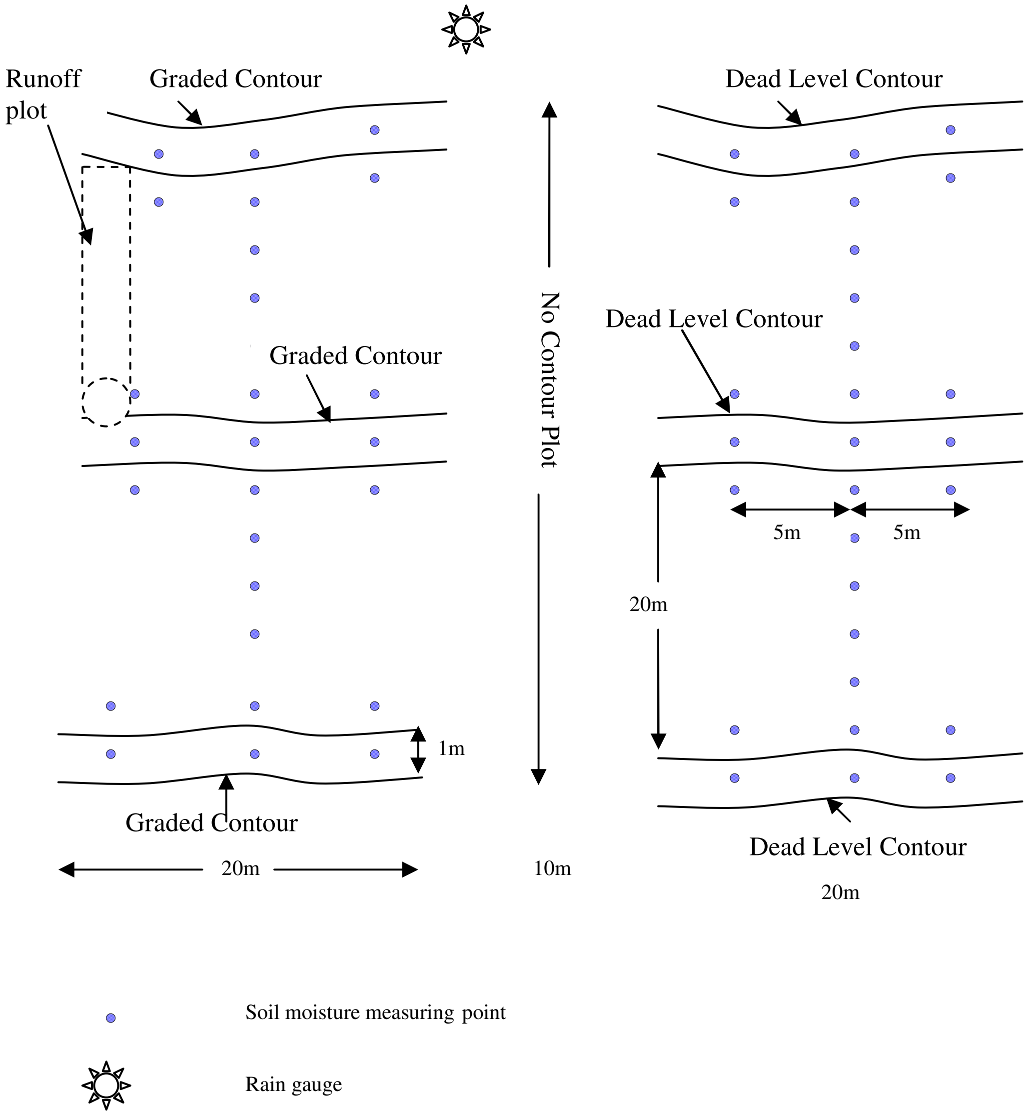

Figure 2: Layout of experimental plots in a farmer's field

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Soil moisture data was measured in the indicated positions. Access tubes (figure 3) were installed in the ground in each position where soil moisture data was required. The moisture content of the soil was measured using The Gopher Soil Moisture Profiler. This is an instrument that measures the moisture content of the soil through measuring the dielectric constant of the soil plus water. An increase in the water content of a soil results in an increase in the dielectric constant of the soil and water. The instrument is inserted into the access tube each time the soil moisture is taken. Two points are measured in each tube at a depth of 250mm to 300mm and 450mm to 500mm. Measurements were done at an interval of at least once a week with some farmer's plots having a higher frequency. A maize crop was planted in the plots between the contour ridges.

Figure 3: A line of access tubes installed in the experimental plots

Data Analysis

Several access tubes were installed in each experimental plot of every farmer's field. The value of soil moisture in the tube varies with time making it difficult to observe a trend in comparison with another tube. Nyagumbo (2002) faced a similar problem when comparing soil moisture benefit of tillage practices. To solve this problem Nyagumbo (2002) developed a soil moisture storage index as a measure of the cumulative soil moisture stored in the soil profile during a growing season. Five steps are followed in coming up with the soil moisture storage index (SWI) for each access tube.

Step 1
The fractional water content for each time step.
Step 2
The water content for each soil horizon is determed as follows;

$S_{\partial z} = \theta_z \partial_z$
Where
$S_{\partial z}$ is the water content for each measured depth ∂z;
θ_z is the fractional water content;
∂_z is the layer thickness.

Step 3

Cummulative water content from surface to a depth z, given by;

$$S_{t,z} = \sum_{i=1}^{i=n} \theta_{t,z_i} \partial z_i$$

Where

S_{t,z_i} is the cumulative water content to depth z at time t for the i^{th} horizon;

θ_{t,z_i} is the fractional water content at depth z measured at time t for the i^{th} horizon.

Step 4

Effective time for each soil measurement date was determined as

$$\Delta t_n = \frac{t_{n+1} - t_{n-1}}{2}$$

Where

Δt_n is the effective time length interval on the n^{th} measurement date;

t_{n+1} is the next measurement date after the measurement on the n^{th} date;

t_{n-1} is the previous measurement date before the measurement on the n^{th} date.

Step 5

The soil water storage index for each area represented by the tube

$$SWI = \sum_{1}^{n} S_{t,z} \Delta t_n$$

Where

SWI is the soil water storage index

Despite the availability of this technique it still remained difficult to compare soil moisture benefits from the three experimental plots using several access tubes. The concept of SWI was therefore extended from one dimensional to three dimensional. This was achieved by considering that a measurement from each access tube is representing an effective area around the access tube. For each time the areal cumulative SWI was divided by the experimental plot area to obtain an average SWI for the plot. Two more steps were then added to the five steps given above.

Step 6

Effective area for each access tube was determined as follows

$$\Delta A_{d,k} = \frac{x_{d+1} - x_{d-1}}{2} \times \frac{y_{k+1} - y_{k-1}}{2}$$

Where

$\Delta A_{d,k}$ is the area effectively represented by the soil moisture measured in the access tube;

x_{d+1} is the distance to the next (d+1) access tube down slope;

x_{d-1} is the distance to the previous (d-1) access tube down slope;

y_{k+1} is the distance to next (k+1) access tube across slope;

y_{k-1} is the distance to the previous (k-1) access tube across slope;

Step 7

The average soil moisture storage index was obtained through dividing the total SWI by the total plot area represented by the line of tubes.

$$ASWI = \frac{\sum_1^n SWI\,\Delta A_n}{A_T}$$

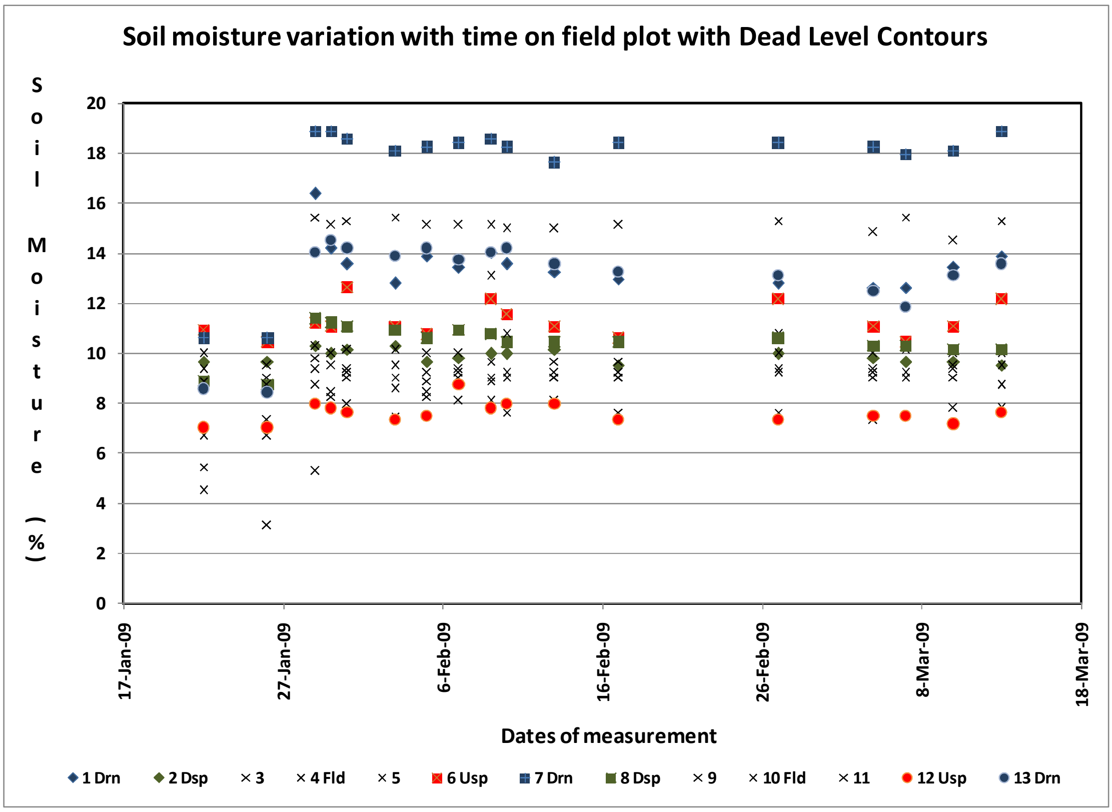
Where

$ASWI$ is the average soil water storage index

A_T is total area of the plot covered by the access tubes.

Results and Discussion

The contour ridges were made at the beginning of the rain season during the last week of October 2008 and first week of November 2008. The access tubes were installed in January 2009 about two months after the commencement of the rain season due to delays in procurement. The soil already contained some soil moisture by the time the access tubes were installed. Since the study is an on farm trial the farmer's land conditions apply.



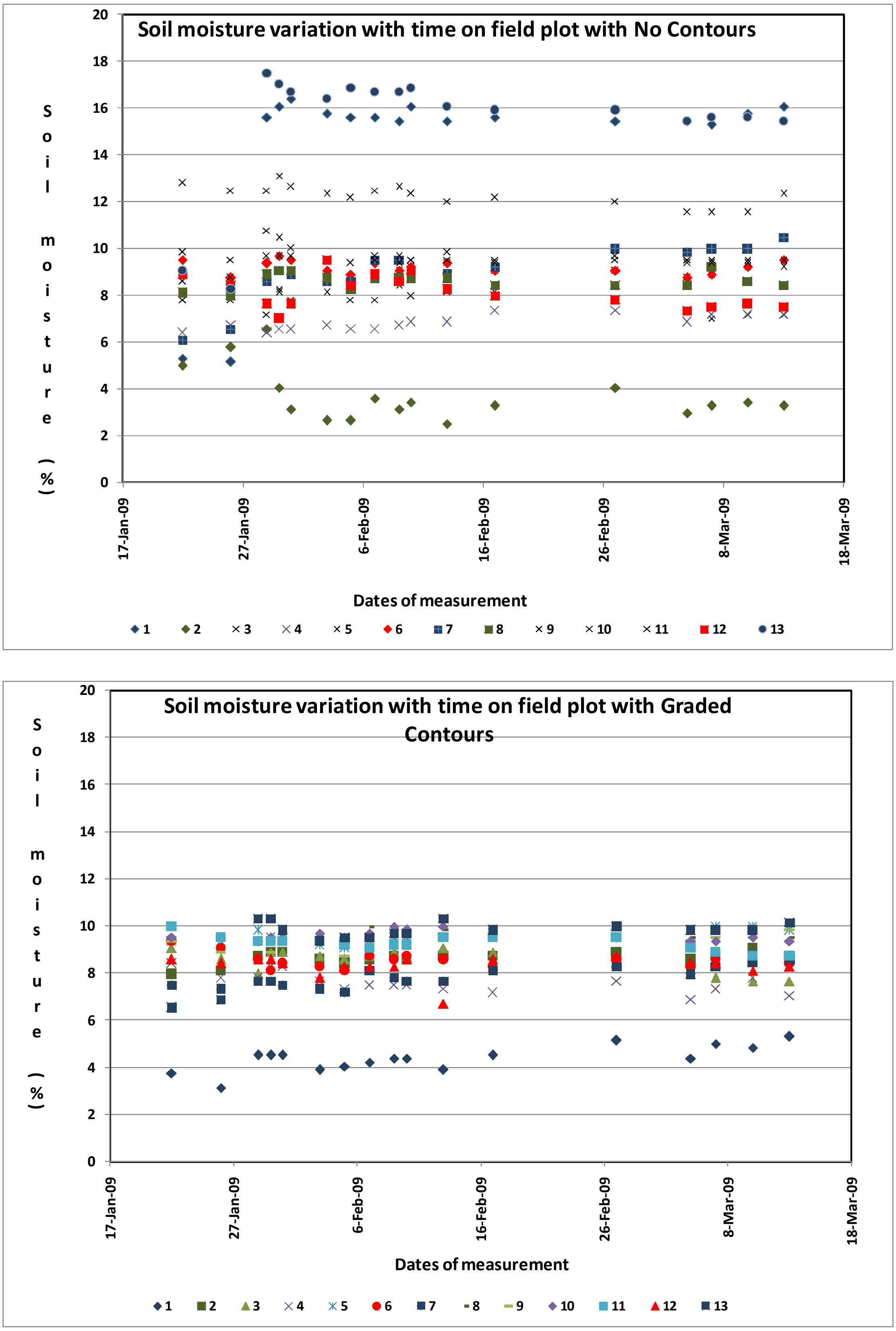
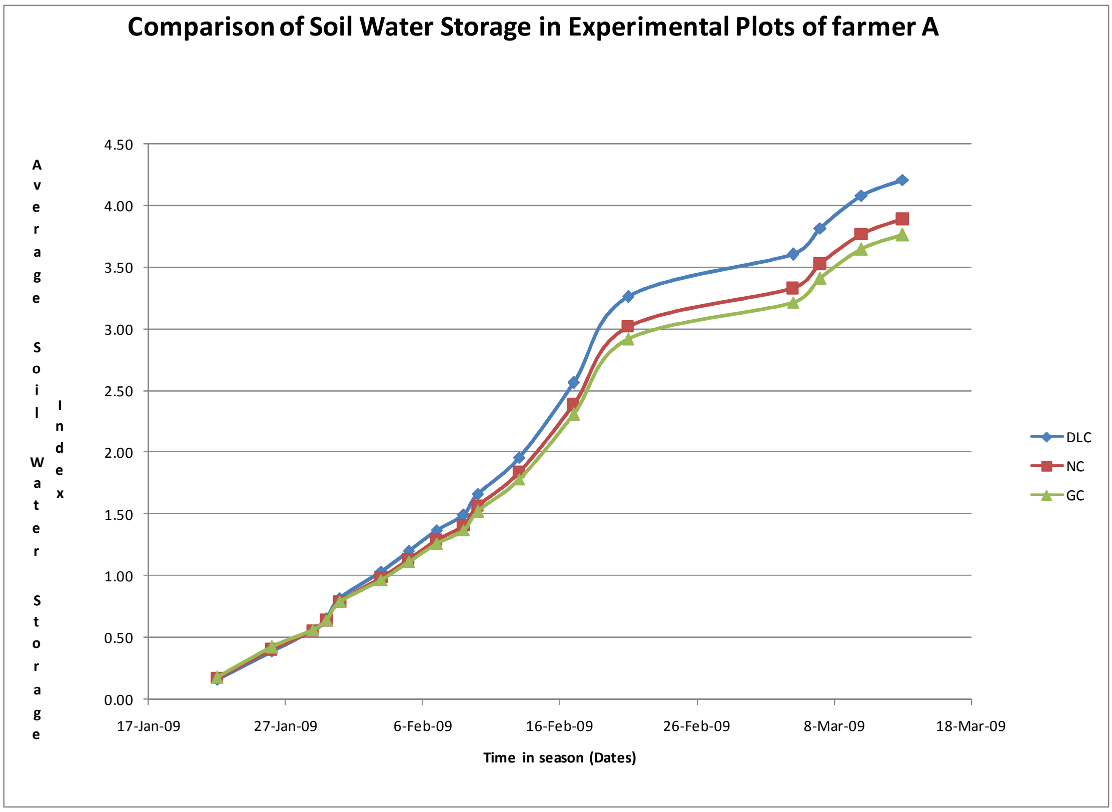
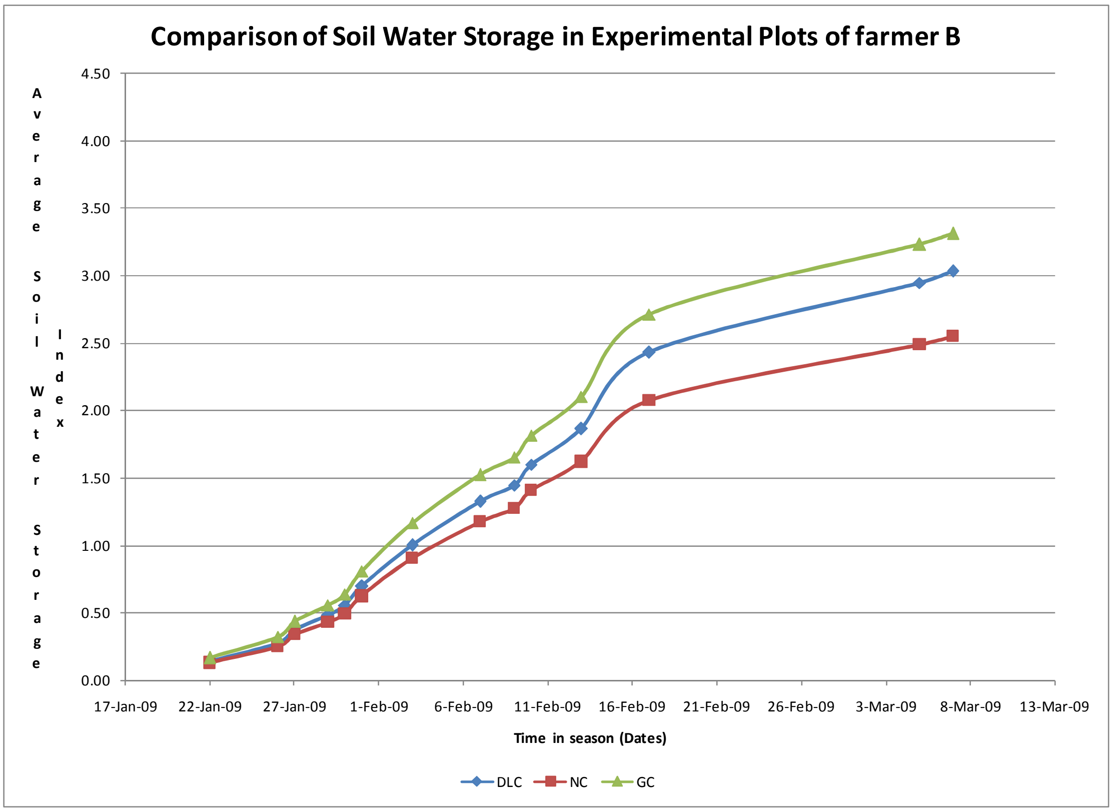
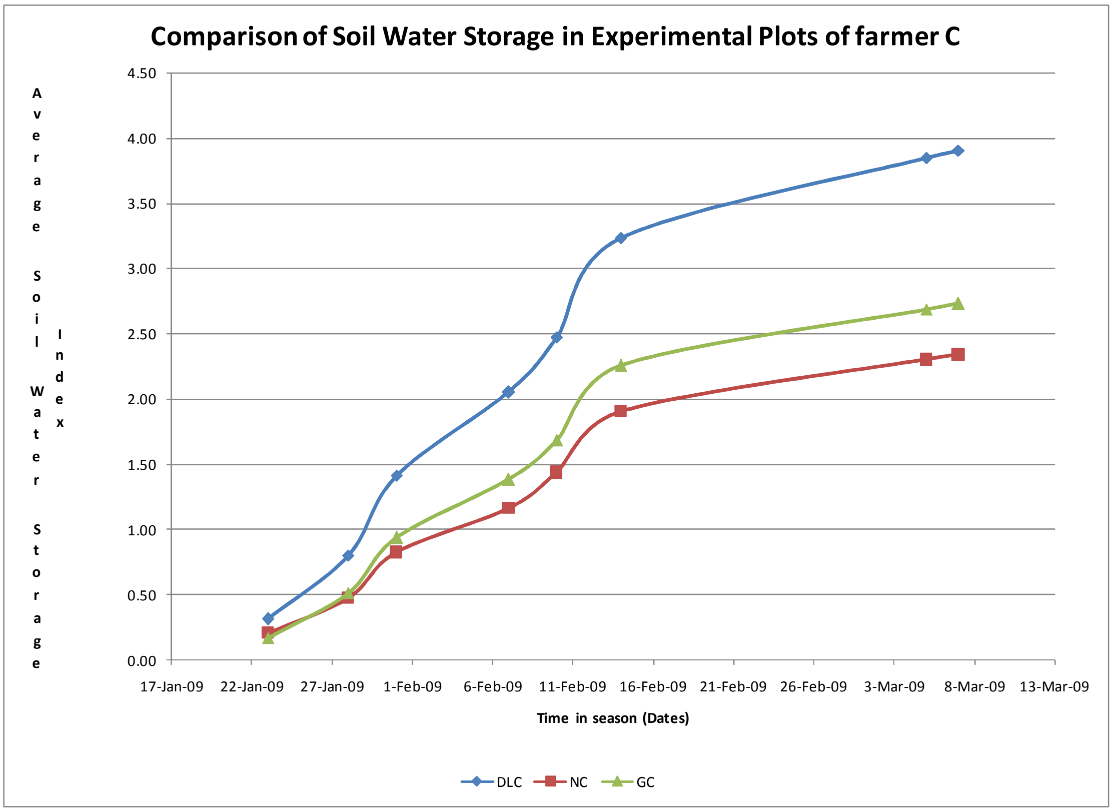


Figure 4: Soil moisture variation for three plots on one of the farmer's field.

Figure 4 shows three graphs of soil moisture variation over time from plots on one of the farmer's field. Several values show an overlap in soil moisture for access tubes from the different plots. The soil moisture in dead level contoured plot appears higher than that from a plot with no contours. When compared to a plot with graded contours the soil moisture in a dead level contoured plot is much higher. However no numerical values can be attached to the results presented in the graphs without further analysis. As a result the soil moisture data was converted into a soil moisture storage index as discussed in materials and methods section.




Comparison of Soil Water Storage in Experimental Plots of farmer B
Average Soil Water Storage Index
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
17-Jan-09
22-Jan-09
27-Jan-09
1-Feb-09
6-Feb-09
11-Feb-09
16-Feb-09
21-Feb-09
26-Feb-09
3-Mar-09
8-Mar-09
13-Mar-09
Time in season (Dates)
DLC
NC
GC


Comparison of Soil Water Storage in Experimental Plots of farmer C
Average Soil Water Storage Index
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
17-Jan-09
22-Jan-09
27-Jan-09
1-Feb-09
6-Feb-09
11-Feb-09
16-Feb-09
21-Feb-09
26-Feb-09
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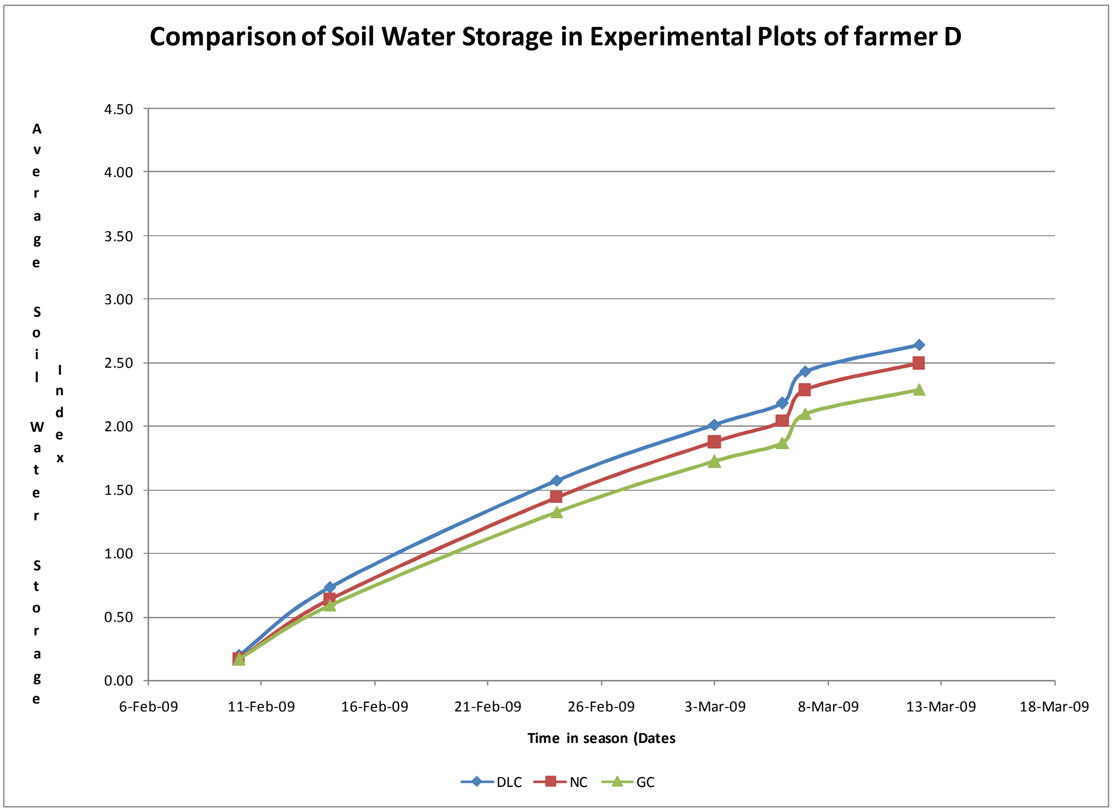
Time in season (Dates)
DLC
NC
GC



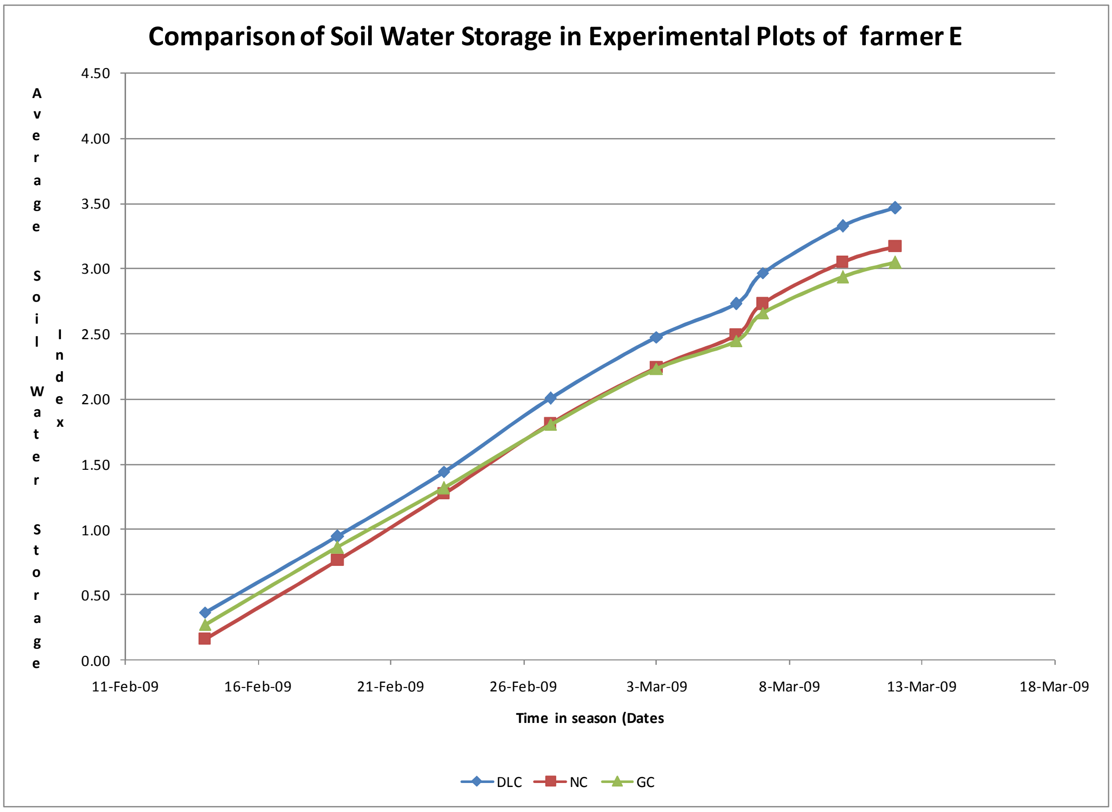


Figure 5: Soil water storage indices for the farmers' fields involved in the study

Figure 5 shows graphs of the soil moisture storage indices for the five farmers' fields. Of the five fields four showed that the soil moisture index of the plot with dead level contours stored the largest amount of water during the period data on soil moisture was obtained. The only field were the dead level contoured plot was exceeded by another plot was on farmer B. In this field a dead level contoured plot was exceeded by a graded contoured plot. Two possible reasons could have caused this. The first and probably most likely reason is that the section of the field where the graded contours were located had an old contour. The new contours cut across the old contour which could have resulted in more water being retained in this plot. The graded contoured plot performed the worst in three out of five plots. This indicates that indeed draining water away from the field using graded contours results in reduced soil water availability in the field compared to either having no contours or constructing dead level contours. In all the five fields a plot with no contours had less soil moisture storage index compared to a plot with dead level contours. This indicates that dead level contours retain moisture in the field.

The study has however not determined whether the difference in moisture retention is significant or whether the larger amount of moisture retention in the dead level contoured plot could result in improved yields

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