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Evaluation of Soil Conservation Structures in Sloppy Lands of Sohawa Area for Soil Moisture and Fertility Conservation

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A B S T R A C T

Pothohar region of the Punjab, Pakistan is rain-fed with undulating topography. Soils of the area are predominantly loose with low water retention capacity and are vulnerable to erosion. Erratic and high intensity rainfall causes land erosion in the area producing gullies and gorges. Therefore, agriculture in the area faces twin menace of soil erosion and moisture stress. On-farm water control structures are among the important measures to control soil erosion and conserve moisture to enhance agriculture productivity. Present study was designed to evaluate the impact of these structures on soil moisture conservation and physio-chemical characteristics of soil in wheat growing fields. Wheat was sown in the fields, with and without structures during 2009 to 2013. It has been found that construction cost of such structures is about one-fourth that of conventionally used structures in the area whereas reduction in soil erosion has been observed up to 10% with 21% soil moisture conservation as compared to control. Soil fertility level improved significantly as a result of reduced run off and nutrient loss. A substantial improvement in wheat yield up to 15% due to increased fertility and moisture content was also recorded. These structures facilitated a safe disposal of surplus rain water which minimized the gully development, improved the soil structure, checked fertility loss and improved soil moisture retention.

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Introduction

Terraced lands are widely distributed in the world (Gardner and Gerrard, 2003) and in most of such areas topography is found undulating with erratic rainfall. The soils of Pakistan across much of the 22 m ha cultivated area, have been formed from calcareous alluvium and loess material, and are low in many essential plant nutrients (Chaudhry et al., 2007). High intensity rains generate surface runoff that flashes over sloppy lands with low organic matter contents, at high speed from higher to lower elevation, causing soil erosion. For the last many decades, land degradation has been an important global concern due to its negative effects on food security and the quality of life (Eswaran et al., 2001; Lal, 2001). To solve the land degradation problem farmers have acquired many cadences including runoff control, soil structure betterment and nutrient management (Mando et al., 2000). Soil and water conservation researchers have emphasized on the embarking the fields by stone lining to check runoff and to control erosion (Mando et al., 2000).

In Pakistan, Pothohar Plateau invades an area of 2.23 mha having uneven topography with direct or indirect contingent rainfall. Almost sixty to seventy (60-70) percent rain is received in months of June to August. The areas receives an average rainfall of 500 mm which is insufficient for uninterrupted cropping (Yousaf, 2007). The main soil problems of Pothohar include soil erosion, soil moisture stress and low soil fertility that are mainly caused by uneven topography and poor management of land and water resources of the area. The farmers have converted sloppy lands into terraces, in order to prevent soil erosion and depletion of soil fertility. Since, most of the Pothohar area comprises of uneven sloppy lands and various fields / terraces are situated at variable slope gradients, so the water received during torrential rains moves from higher to lower fields resulting into soil erosion and gully formation. Since, two third rainfall of the year is received in a short period of three months (i.e., June to August) usually in high intensities which sometimes go as high as 100-160 mm hour^{-1}. When this high intensity rainfall is not managed properly, it causes tremendous amount of soil erosion, fertility loss and water runoff, leaving behind unproductive lands and inadequate water quantity for crops. In arid areas (i.e., areas with an annual rainfall below 200 mm), it is best to encourage and collect the runoff from a barren catchment area, and lead it to a cropping area (Hudson, 1987).

For minimizing erosion and promoting sediment deposition, terrace structure is a barrier constructed of stones that reduces the flow velocity of runoff. While to slow down and filter runoff contour stone bunds are used, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to ameliorated crop functioning. For small scale application this technique is well fitted on farmer's fields. It can be carried out quickly and stingily if adequate supply of stones can be facilitated. These stone structures can play vital role in harvesting enough runoff and can improve soil moisture leading to better fertilizer use efficiency. Moreover, the structures defend fields from caustic effects of heavy/erratic rains. Presently, concrete structures are being built for bedeviling the flow of water from one field to the other. The concrete structures are very expensive and not affordable for resource poor farmers of the area. Hence, the present study was initiated to evaluate the effect of cost-effective loose stone structures which can easily be built and handled the soil erosion under high rainfall area of Sohawa, District Jhelum.

Farmers keep land fallow during high intensity summer rainfall periods, resulting in runoff, soil and fertility losses consequently low agriculture productivity. Erosion deteriorates several soil properties, such as thickness of fertile layer of topsoil, soil organic matter content, nutrient status, soil texture and structure, available water holding capacity and water transmittance characteristics. All these characteristics in concrete baffle soil quality and affect crop yield (Kaihura et al., 1999). The overall objectives of this study are; -to evaluate performance of On-farm water control structures (OFWCS), -to assess their cost effectiveness to be used for safe disposal of surplus water-runoff across the fields, -to conserve the rainfall water in the fields for soil-moisture improvement and their essence on crop yield.

Materials and Methods

Site Description

On-Farm Water Control Structures (OFWCS) were developed at Khabbal near Soil and Water Conservation Research Station (SAWCRS) Sohawa district Jhelum, having latitude 32.51° N, longitude 73.00° E and elevation of 508 m above mean sea level. The structures were developed on sloppy terraced lands vulnerable to gully formation. The site area is characterized as semi-arid to humid with an annual rainfall of around 700-1000 mm. During the years 2009 to 2013, annual rainfall varied from 700 mm to 1000 mm. Rainfall is summer dominant and only about 30% of the average annual rainfall occurs during the wheat growing season (October-April). The soils of the area are classified as moderately deep, well drained, fine textured, calcareous loess deposited (Reconnaissance Soil Survey, Campbellpur, 1970).

Experimental Details

Experiment was carried out during 2009-13 on an agricultural land having the uniform soil texture and slope, divided into two equal blocks. Wheat crop (the variety, CHAKWAL-50) was sown in these experimental blocks. In one block OFWCS were constructed while other was left without structures to compare the efficiency in conserving soil, moisture, fertility and crop yield with the block having no structures. Both blocks were further divided into two sub-blocks for recommended nutrient dose (NPK@120, 80, 60 kg ha^{-1}) and farmer's practice. Recommended dose of mineral fertilizers was applied during each season of entire experimentation period (i.e., 2009-2013) whereas in farmer's practice, farmer applied the FYM @1 ton ha^{-1} after every two years and urea @ 50 kg ha^{-1} every year.

Designing of On-Farm Water Control Structures

For calculation of discharge (Q), the values of rainfall Intensity (I), runoff Coefficient (C) and Area of catchment above fields (A) are needed. For the purpose of designing OFWCS, a return period of 50 years was taken, the value of Intensity (I) has been assumed as 4 inches per hour. The runoff coefficient (C) was taken as 0.4 for the cultivated land, slope varying from 0-5 % for medium soil of the area. Therefore, on basis of the average values of rainfall intensity (I) and runoff coefficient (C), peak discharge (Q), the Rationale formula was used as given:

$Q = CIA$ $Q = 1.6\ A$

A = Area in acres

The structure as shown in Figure 1 was designed by using broad crested weir formula developed by using simplified formula of Weir (Engineering field manual SCS) as given below:

$$Q = \frac{3.1\ L\ h^{1.5}}{1.10 + 0.01F}$$

Where;

h = Total depth of structure, in feet (including free board)

F = Net drop in feet

L = Length of the structure in feet

(FAO Field manual of Agricultural Engineering, 1990)

Performance Evaluation of OFWCS

The On-Farm Water Control Structures were visited after every rainfall event and the following data were recorded for evaluation of their performance:

- Displacement of stones;
- Settlement of stones due to undermining/piping or surface soil loss;
- Erosion/gully development at down stream and up stream of the structures;
- Hydrological/drainage performance of structures;
- Crop yield in upper field in relation to control and
- Impact of OFWCS on physio-chemical properties of soil.

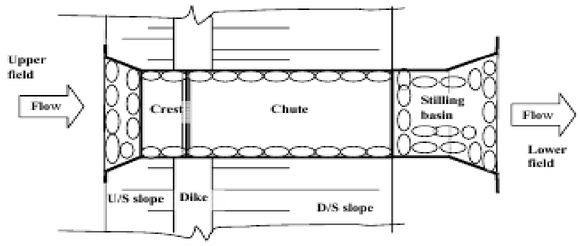

Figure 1 Schematic layout plan of a terrace structure

Cost of OFWCS

The conventional structures, commonly known as spillways/outlets being constructed to control erosion are made up with bricks-cement or cement-concrete and/or both. Their cost ranges from Rs. 30,000 to Rs. 100,000 per structure depending upon the length and depth of structure. For current study, loose stones were used to construct the structures without using any cementing agent (Figure 1). Grasses were established naturally in these structures during one to two seasons, which acted as binding agent for these structures. Therefore, the cost of these OFWCS was far less than the cost of structures made by using cement, bricks and concrete. The average cost of these loose stone structures was worked out to be about Rs. 5000 to Rs. 25000. An additional benefit of these structures is harvesting of adequate runoff, so there is an improvement in soil moisture and positive crop response to fertilizer. As a result, crop yield increases by 20-25% corresponding to the results reported by Akhtar et al., (2004).

Soil Sampling and Analysis

A composite soil sample was collected from the study area to carry out physio-chemical analysis before initiating the work plan. Thereafter, soil samples were collected from 0-15 cm before sowing of wheat from each main block and sub-blocks to estimate moisture and physio-chemical properties to assess the changes in soil after installation of OFWCS (Figure 5 and Figure 6). Samples were air-dried and sieved through 2 mm sieve before chemical analysis. Soil pH, organic matter, extractable K and soil available P were determined by the methods described by (McLean, 1982), (Richards, 1954), (Walkley, 1947), (Rhodes, 1982) and (Watanabe and Olsen, 1965) respectively, while soil texture was determined by Bouyoucus method (Gee and Bauder, 1986). Soil moisture contents were determined by gravimetric method (American Society of Agronomy, 1965). All samples were analyzed in the laboratory of Soil and Water Conservation Research Station, Sohawa and results are presented in Table 1.

Crop Data

At the end of each growing season, wheat crop was harvested manually selecting a plot size of 1×1 m^2. The samples were then thrashed and weighed for grain yield and straw production.

Rainfall and Mean Monthly Temperature

Rainfall and mean monthly temperature were recorded at experimental site and are presented graphically in Figure 2a and Figure 2b respectively.

Statistical Analysis

Statistical analysis of the data was carried out using methods described by Steel and Torrie, (1997).

Results and Discussion

Performance Evaluation of OFWCS

Detailed description of the parameters considered for performance evaluation and stability of OFWCS is given in the following sections:

Displacement of Stones

To observe the stability of structures, displacement of stones was monitored after every rainfall event during and after the growing season. It was observed that during first year of the experiment, stones were frequently displaced after rainfall events caused runoff. Displaced stones were therefore re-fixed eventually. However, after one year, grasses were developed that acted as binding agent and hence strengthened the loose stones, which were then rarely displaced.

Table 1 Physico-Chemical characteristics of experimental site

pH	EC_e (dS m^{-1})	O.M. (%)	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	Saturation (%)	Texture
7.50	0.56	0.33	5.50	180	24.0	Sandy Loam

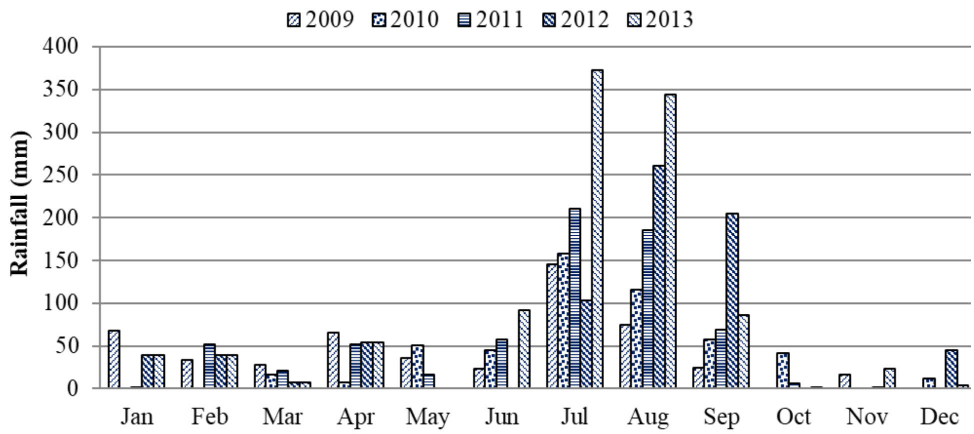

Figure 2(a) Monthly rainfall of the area

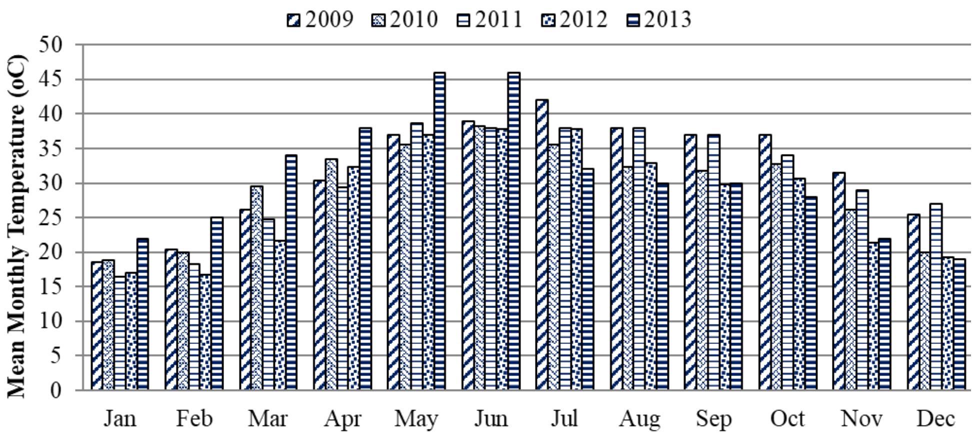

Figure 2(b) Mean monthly temperature of the area.

Settlement of Stones Due to Piping Action and/or Surface Soil Loss

It was observed during the study period that with the passage of time grasses were developed and gaps among the loose stones were filled with soil retained by the grasses, which then settled the stones. It had been observed that the performance of these structures improved with time on settlement of loose stones and bounded on the growth of grasses within the structure No major damage to these structures was observed during the study period except the first year of establishment of OWFCS. Since the purpose of the structures was to intercept or to reduce the velocity of run off, it was noticed that these structures helped in reducing runoff which consequently enhanced the infiltration of rain water in the fields above structures. Higher moisture readings in fields above structures as compared to fields without structures. However, during high intensity rainfall events in 2009 and 2013 some stones were settled due to piping action.

Erosion Above and Below the Structures

The major success of these structures was that they greatly minimized the erosion and gully development in upper and lower fields. They acted as dike and energy dissipaters that reduced the runoff velocity in upper fields as well as worked as spillway, dissipating the energy of flowing water. These structures had safely disposed the surplus rain water. However, minor rills found at downstream were repaired. The stones acted as a filter for coarse sediment during major rainfall events similar to as described by (Nyssen et al., 2000). Nasri et al. (2004) reported that well maintained water harvesting systems are able to infiltrate all runoff. Similar observation was noted during current study. Gorges and gully development was observed in fields without structures.

Hydrological/Drainage Performance of Structures

Depth of rain water passed over the crest of structures, was measured for events causing runoff. Generally the events above 20 mm produced runoff and water passed over the structures. Data of rainfall and runoff depth passed over the structures is summarized in table 2. It has been observed that these structures tolerated the highest event of 115 mm received in 2009, as no major damage to structures was observed. However some stones were settled during 2009 and displaced because the structures were fresh and stones were too loose as no grass was developed to work as binding agent. Similarly all peaks of rainfall runoff ranging from 6.25 mm to 25 mm depth were safely passed over the structures.

Crop Yield in Fields with and Without Structures

There are several techniques and practices being used to conserve moisture and check soil erosion, OFWCS is one of these techniques. OFWCS are established to improve the agricultural productivity of cultivated soils in sloppy lands. Wheat is the most important crop of the area. When OFWCS were tested in terms of their response to wheat production, results were quite encouraging and it was noticed that these structures improved the crop yield significantly (Figure 3). Maximum crop yield (3702 Kg ha^{-1}) was recorded in 2010-11 in plots with structures sown under recommended fertilizer dose (RDWS) which was 8% higher than fields with structures under farmer’s practice (FPWS) during the first year. Almost the same trend was noticed in every year. During the entire experimental period (2009-2013), it was observed that wheat yield in RDWS was 15% higher as compared to the yield from plots with no structure (RDWOS), 5% as compared to FPWS and 21% as compared to FPWOS which revealed a significant increase in wheat yield by OFWCS.

Table 2 Effect of highest rainfall event on structures

Year	No. of rain storms ≥ 20 (mm)	Total rainfall (mm) July to June	Highest rainfall event (mm)	Height of water passed over the crest (cm)
2009	9	696	115	11.00-25.00
2010	5	463	42	6.25-9.50
2011	6	464	33	8.00-15.00
2012	8	611	55	7.50-13.50
2013	5	970	63	9.75-16.50

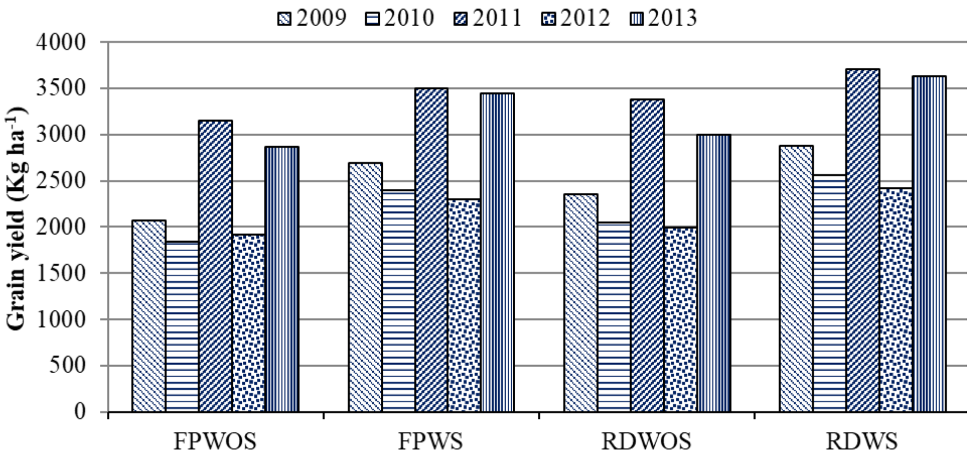

Figure 3 Variation of crop yield under various treatments

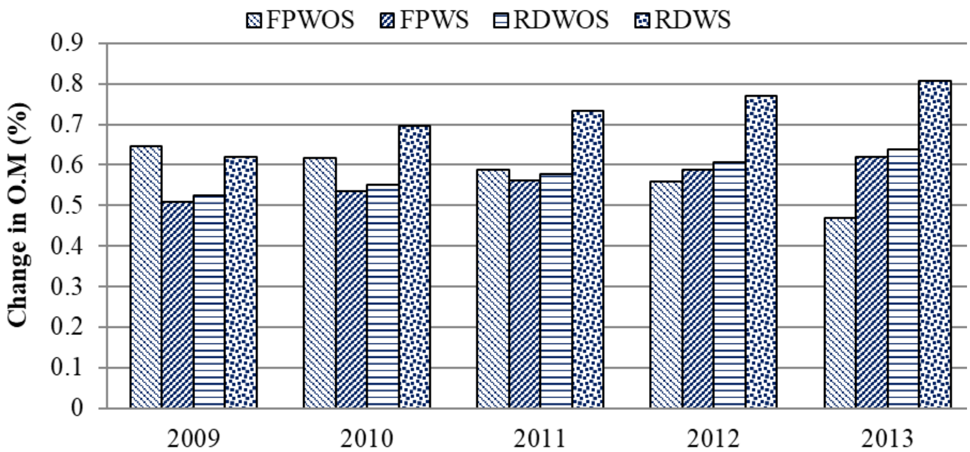

Figure 4 Variation of soil organic matter under various treatments

The response was best and evident in RDWS which may be attributed to reduce the soil and water erosion losses. Since lands in the area are sloppy with loose soils which are vulnerable to run off and erosion. OFWCS minimized the magnitude of soil erosion losses and soil fertility depletion through run off as these structures provide more time for water infiltration leading to conserve soil moisture. Prinz et al., 1996 also described that the structures work as soil moisture conservation practice and can be used for restoration of the productivity of such lands which suffers from moisture shortage. The potential short-term benefits of stone bunds are the reduction of slope length and creation of small retention basins for runoff and sediment (Bosshart, 1997).

These structures reduced the volume and erosivity of the overland flow, resulted in reduced soil loss. In the long term, slow-forming of terraces induced by stone bunds are often associated with a high spatial variability in soil fertility and crop response. Stone bunds technology helped to increase the grain yield up to 53% in most soil types as described by (Vancampenhout et al., 2003). Investigation of Elamin (2010) describes as the water harvesting techniques significantly increased the water storage capacity of the soil which significantly increased the grain yield by 43%. Alemayehu et al., (2006) in his study indicated that indigenous stone dikes have a positive effect on crop yield. A five year experimental study of Zougmore et al., (2002) showed that stone lines, have a limited effect on soil fertility and crop productivity. The explanation by Shemdoen et al. (2009) confirms that performance evaluation through crop yield alone is not fair because crop performance is a function of many factors including soil fertility, soil water availability and weed competition. On eroded soils yield can be improved by balanced application of fertilizers (Izaurralde et al., 2006).

Impact of OFWCS on Physio-Chemical Properties of Soil

Effect on organic matter: OFWCS revealed a significant effect on soil organic matter (O.M) nevertheless soil and water conservation practices require long time to mark any serious impact because soil and water erosion with run off did not allow to develop soil structure and sweeps away all the top soil. Data recorded under this study showed that an average maximum organic matter content of 0.81% was recorded in RDWS followed by 0.64% in RDWOS while the lowest organic matter content of 0.47% was estimated in the treatment FPWOS (Figure 4).

Holechek et al. (1989) reported that in dry land the effect of soil and water conservation management takes a long time to be apprehended. Khan et al. (2003) observed decrease in organic matter with increase of erosion and vice versa. Top soil loss with water erosion, nutrient mining with centuries old cropping, no crop residue recycling or green manuring and inadequate fertilizer use have led to the reduced content of soil O.M. throughout the Pothohar plateau (Rashid and Qayyum, 1990). Worku Hailu (2017) also concluded that soil organic carbon (SOC) was higher when soil and water conservation structures were applied than control plot.

Effect on soil moisture: The major concern of the farming community is moisture stress in soils and is the main objective of this study. From the analysis of data on soil moisture contents it has been observed that OFWCS has significantly enhanced the soil moisture contents (Figure 5). Results revealed that the gravimetric soil moisture contents were improved upto 13% especially in RDWS every year. Five year data revealed that average maximum moisture contents of 11.23% were recorded in RDWS. Vancampenhout (2003) and Nyssen et al., 2000 found that stone bunds enhance soil moisture storage on both sides of the bund, especially on loamy and sandy soils. Hudson (1987) and Schwab et al. (1993) in their study observed an increase in soil moisture in upper layer of the soil profile. However, water that has percolated to greater depth is less available for evapotranspiration and hence offers possibilities for deeper root zone recharge (Scott et al., 2000) and groundwater recharge (Prinz and Malik, 2005). Fu et al., (2003) reported that temporal changes and variability of soil moisture are affected and controlled by topography, soil types, vegetation, land use and management practices.

Soil management reduced the surface runoff which had accelerated infiltration and consequently increased soil moisture stored in the soil profile. A similar result was observed by other researchers like (Al-Kharabsheh, 2004) and (Mugabe, 2004) who found that water and soil management practices, such as stone terraces, ridges and furrows significantly increases soil moisture storage over that in untreated areas. Control structures are needed to store more rainwater and make it available for plants uptake, erosion control and soil fertility improvements (Rockstrom and Falkenmark, 2000).

Effect on chemical characteristics: Nutrient indexing survey of wheat in Pothohar areas indicated that 70% fields were deficient in N, 67% in P, 20% in K, 64% in B and 70% in Zn (Rashid, 1990). In Pakistani soils P, Zn and B deficiencies are due to high pH, calcareousness and low organic matter that are further accelerated by erosion hazards (Ahmad and Rashid, 2003). In general, the nutrient level of studied soils was low particularly that of phosphorus, perhaps because of less physical protection against water erosion, and limited nutrient supply. The sloppy lands have been cultivated continuously, with limited investments in soil and water conservation and nutrient amendments. This has led to soil erosion and nutrient depletion thereby escalating the risk of land degradation. Runoff causes erosion of fertile topsoil, resulting in soil degradation (Schiettecatte et al., 2005).

Effect on available phosphorus: The average available phosphorus values in plots with and without structures were recorded for all treatments and is shown in Figure 6.

It was found that available phosphorus under recommended dose practices was increased during the study period. Mean of available phosphorus was observed in order of RDWS > FPWS > RDWOS > FPWOS. Almost the similar behavior was noticed in all treatments every year. This might be due to availability of higher soil moisture and reduced run off that increased the availability of soil Phosphorus through mineralization. Glendinning (2000) found that in most soils, the amount of organic-P is highly correlated with the amount of organic-C; the rate of mineralization of organic-P increases as the organic-P content of the soil increases. That is, the more organic-P there is in the soil, and the faster it is mineralized to be converted into available forms for plants uptake. The stabilization of O.M through reduced soil and water losses in OFWCS might have enhanced the availability of phosphorus. The overall inadequacy of available phosphorus on all experimental sites could be due to the parent material; the low record of available phosphorus content might be because of the erosion. Anyhow, the available P from non-structured soils was decreased with the passage of time at all locations might be due to run off. These results are in line with Vancampenhout (2003) who noted that available phosphorous was higher in the accumulation zone than in the soil loss zone in non-conserved lands. Gete (2000) also studied that erosion can lead to the removal of available phosphorus including other nutrients from the top soil.

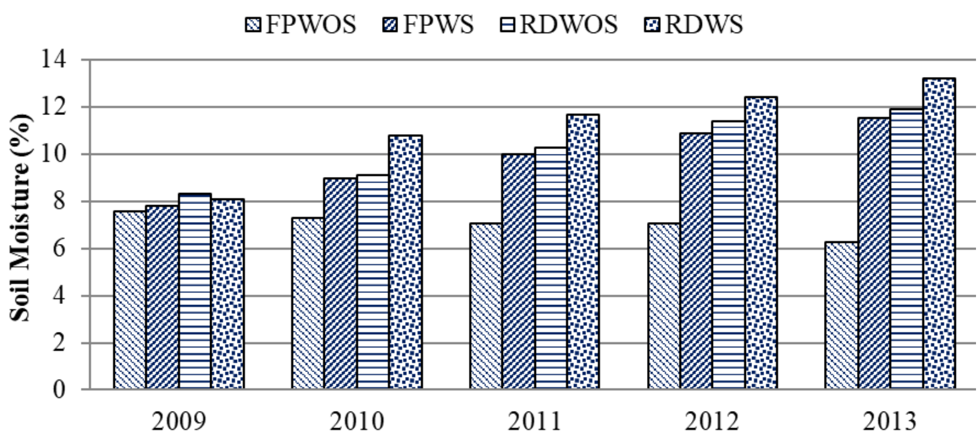

Figure 5 Variation of soil moisture under various treatments

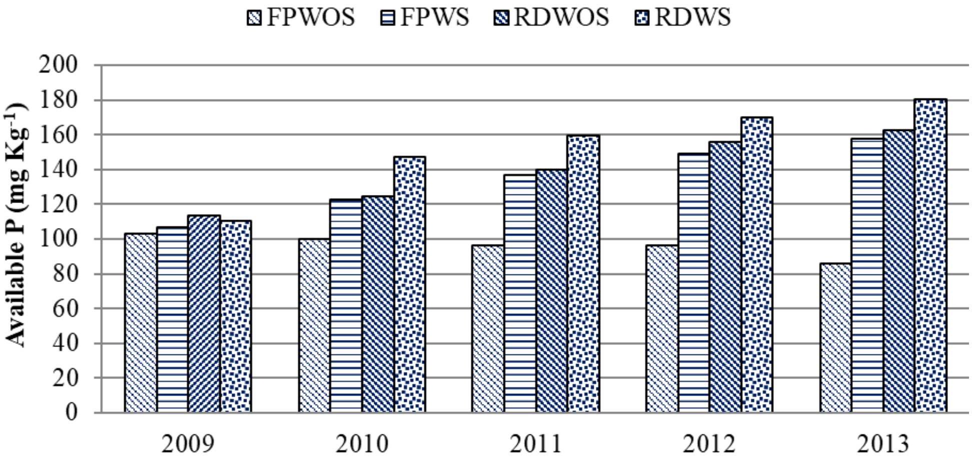

Figure 6 Variation of available phosphorus under various treatments

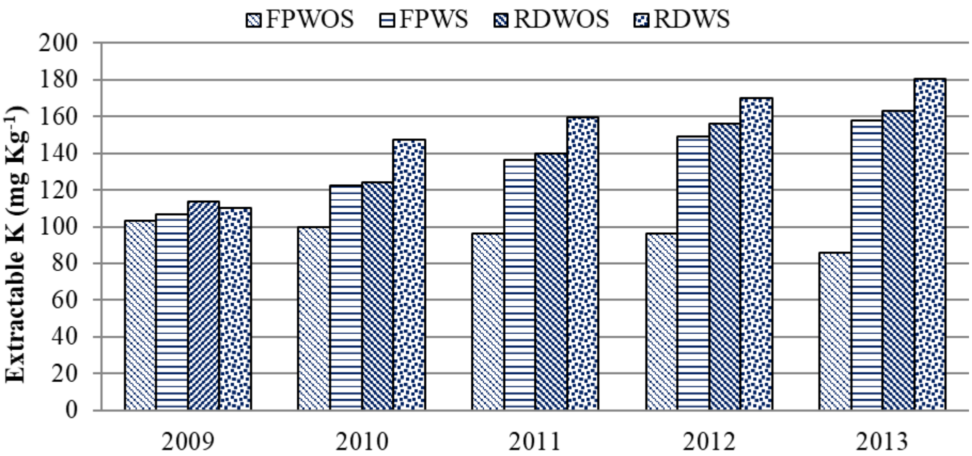

Figure 7 Variation of extractable potassium under various treatments

Effect on extractable potassium: Soil samples from plots with and without structures under all treatments were collected and analyzed. The results revealed that the average extractable potassium contents were increased in plots having structures particularly in RDWS from 45 to 79 mg kg^{-1}. But, run off from plots without structures decreased the K level (41 to 38 mg kg^{-1}) especially in FPWOS which could lead to fertility depletion. This phenomenon is depicted in Figure 7. Similar observation was made by Xiao-yan et al. (2004). In-situ water conservation practices have long been utilized as a measure to reduce soil erosion, sedimentation and to increase soil water storage and soil fertility. Glendinning (2000) asserted that soils of low CEC have little ability to store potassium and large applications of this element are likely to be used very inefficiently by the plant and lost by leaching. Abu Hammad et al., 2006 concluded from his experiments that soil and water conservation practices reduce the negative effect of intense rainfall by decreasing the amount of runoff and erosion and significantly increase the amount of soil organic matter, Mg, Ca, and K. Morgan et al., 2005 also reported that OFWCS's are practically used as support for agronomic and soil management and considered as the first defense line.

Conclusions and Recommendations

From this study it has been concluded that there was an increase of 15% crop yield by installing OFWCS. Soil characteristics were also improved for better crop cultivation and root development. Soil moisture contents were enhanced up to 21%. By reduction in runoff and in-situ soil moisture conservation an appreciable decrease in gully development and soil sediment loss was observed.

The study strongly recommends farmers to adopt integrated nutrient management practices along with soil and water conservation measures by installing OFWCS, which are desperate to protect their lands from impairment and degradation.

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