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Evaluation of Loose Stone Terrace Structures for Soil Moisture and Fertility Conservation in Sloppy Lands of Attock District, Pakistan

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Abstract
Loose Stone Terrace Structures (LSTS) are among the important measures to enhance the water conservation and to obtain maximum crop yield. Present study was designed to evaluate the impact of LSTS on soil moisture conservation, wheat yield and physico-chemical characteristics of soil. Wheat was sown on the upstream of LSTS consisting of two major blocks; one with structure and other without structure while under both there were two sub-blocks; one with recommended dose of fertilizer and other with famer practice. In this way there were four treatments including Recommended Dose with Structure (RDWS), Recommended Dose without Structure (RDWOS), Farmer Practice with Structure (FPWS) and Farmer Practice without Structure (FPWOS). The economic evaluation of the structures indicated that the LSTS (average cost US$ 35.85 per structure) is very cost-effective. LSTS enhanced profile soil moisture retention up to 21% by reducing run off and wheat yield was increase up to 15% in RDWS. Soil fertility level improved significantly, trend revealed that LSTS have conserved the soil nutrients by minimizing the run off and soil sediment loss. It was also noticed that gully development was minimized greatly due to the safe disposal of surplus rain water which had improved the soil structure of cultivated lands and stopped fertility depletion.
Keywords: Loose stone structures, water-harvesting structures, rainfed, wheat production

INTRODUCTION

Terraced lands are widely distributed in the world (Gardner and Gerrard, 2003). Erratic rainfall and loss of water through runoff are major limitations in the sloppy lands. The loss through runoff is occurred by the high intensity of the rainfall and due to low organic matter content of the soils. Land degradation has been an important global concern for the last many decades due to its negative effects on crop productivity and its impact on food security and the quality of life (Eswaran et al. 2001; Lal, 2001). To solve the degradation problem, farmers have developed many measures, including runoff control, soil structure improvement, and nutrient management. 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, the Pothowar Plateau occupies an area of 5.49 million hectare having uneven topography and is directly or indirectly dependent on rainfall. Almost 60-70 percent rainfall occurs in months of June to August. The areas receiving rainfall less than 500 mm are not suited to continuous cropping due to shortage of water supply (Yousaf, 2007). It is quite tough for a farmer in the Pothowar region of Pakistan. Poor soils, erosion and lack of irrigation characterize the farms in the area. Farmers grow sorghum *(Sorghum bicolor),* millet *(Pennisetum americanum)* and groundnuts *(Arachis hypogea)* in the Kharif (summer); and wheat *(Triticum aestivum)*, mustard *(Brassica compestris)*, gram *(Cicer arietinum)* and lentil *(Lens culinaris)* in the Rabi (winter). Most of the cultivated land is *Barani* (rainfed), so farmers depend on low and erratic rainfall. For a farmer in *Barani* areas in Pakistan, rains can be a nightmare. This tract has lot of potential for raising crops which can significantly play an important role in the economy of the country. The main soil problems of Pothowar include soil erosion, loss of soil water and low soil fertility due to uneven sloping topography. In order to prevent soil erosion and depletion of soil fertility, the farmers have converted sloppy lands into terraces. Currently, most prevalent cropping pattern on these terraces is Wheat-Fallow. Since, most of the area of Pothowar is not flat and various fields / terraces are situated at variable slope gradients. The water received during torrential rains moves from higher to lower fields resulting into soil erosion and gully formation. About two third rainfall of the year is received in summer (July to September) usually in high intensities which sometimes go as high as 100-160 mm hour^{-1}. It causes tremendous amount of soil erosion and water runoff, if unmanaged, leaving behind infertile land and inadequate available water 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 (Poesen *et al.* 2003) and Bellin *et al.* 2009 also revealed that traditional rainfed agriculture in semi-arid regions heavily relies on soil and water conservation structures to supplement the sparse rainfall.

LSTS is a barrier constructed of stones that reduce the flow velocity of runoff, while minimizing erosion and promoting sediment deposition. Contour stone bunds are used to slow down and filter runoff, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to improved crop performance. This technique is well suited to small scale application on farmer's fields and, given an adequate supply of stones, can be implemented quickly and cheaply. The structures can harvest adequate runoff and can improve soil moisture and positive crop response to fertilizer. Furthermore, the structures protect fields from destructive effects of heavy rains. The present practice for addressing this issue is construction of concrete structures for regulating the flow of water from one field to the other is beyond the access of the poor farmers in these areas. Therefore, to furnish the cost-effective technology, this study was started to evaluate their effectiveness. During high intensity summer rainfall farmers keep land fallow, it resulting in runoff losses and low productivity. Erosion influences several soil properties, such as topsoil depth, soil organic carbon content, nutrient status, soil texture and structure, available water holding capacity and water transmission characteristics. All these together regulate soil quality and determine crop yield (Kaihura *et al*., 1999). The overall objectives of this study were; LSTS performance evaluation and for their cost effective standardization, Conserve the rainfall water in the field and allow safe disposal of surplus runoff water across the fields & improve the soil-moisture in the upper field and their effect on wheat grain yield.

MATERIALS AND METHODS

Site Description

LSTS were developed at *Dhok Hafizabad* (Jand), Pakistan (latitude 33.47° N, longitude and 72.21° E and 398 m high from the sea level) of district Attock, which were developed on sloppy terraced lands prone to gully formation. The site have semi-arid climate with an annual rainfall of around 500-700 mm. Between 2005 and 2010, annual rainfall ranged from 409 mm to 641 mm. Rainfall is summer dominant and only about 30% of the average annual rainfall occurs during the wheat growing season (October-April). The soils have been classified as moderately deep, well drained, fine textured, calcareous loess deposited (Reconnaissance Soil Survey, 1970).

Experimental Details

The experiment was carried out during 2005-10. Wheat was sown at upstream of structure to compare the efficiency of LSTS compared to non-structured field and its effects on crop yield, soil moisture conservation and on soil nutrient status. Both structured and non-structured blocks were further divided into two sub-blocks for recommended nutrient dose (NPK@120; 80; 60 kg ha^{-1}) and Farmer practice. In the recommended dose, recommended rates of fertilizer nutrients were applied before sowing of wheat each year. In farmer practice, farmer applied the farm yard manure @1 ton ha^{-1} after every two years and urea @ 50 kg ha^{-1} every year. Wheat variety *Aquaab-2000* was sown every year.

Procedure for Designing of LSTS

For calculation of discharge (Q), the values of rainfall Intensity (I), Coefficient (C) and Area of catchment are needed. For the purpose of designing LSTS for a period of 30 years, the value of Intensity (I) has been assumed as 4 inches per hours. The coefficient of runoff (C) was taken as 0.4 for the cultivated land, slope varying from 0-5 % and medium soil of the area. Therefore, on basis of the average values of rainfall intensity (I) and coefficient of runoff (C), peak discharge (Q) by the Rationale formula can be estimated as:

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

A = Area in acres

The structure can be designed by using broad crested Weir formula developed by using simplified formula of Weir (Engineering field manual SCS).

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

Where

H =Total depth of structure, in feet (including free board)
F = Net drop in feet
L = Length of the structure in feet

(Ali et al. 2007)

Performance of LSTS

The LSTS 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 or surface soil loss.
- Erosion/gully development at down stream and up stream of the structures.
- Hydrological/drainage performance of structures.
- Yield of crops in upper field in relation to control.

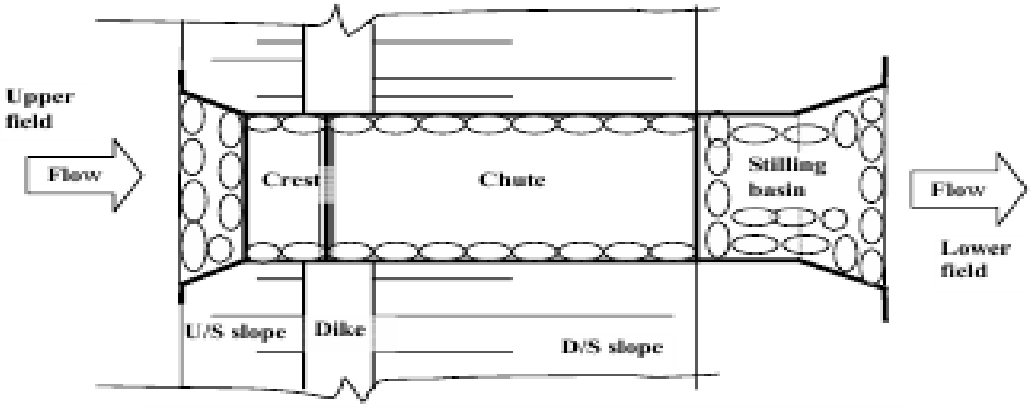


Fig. 1 Schematic layout plan of a LSTS

Cost of LSTS

The cost of the traditional structures known as spillways/outlets usually ranges from US$ 200-1000. These spillways are made of bricks and cement. During this study project only LSTS were developed without cementing agent. After one or two seasons, grasses were established naturally in these structures, which gave strength to these structures. Therefore, the cost of the LSTS was far below than those of cement and brick structures. The average cost of the LSTS was US$ 35.85.

Soil Sampling and Analysis

A composite soil sample was collected from the study area before the initiation of the work plan to carry out physico-chemical analysis (Table 1). Thereafter, soil samples were collected from 0-20 cm before sowing of wheat from each treatment for soil moisture estimation and for physico-chemical determinations to assess the change in soil fertility and physic-chemical properties due to LSTS. Samples were air-dried and sieved through 2 mm sieve before chemical analysis. Soil pH and EC_e were determined by the methods described by McLean (1982) and Richards (1954) respectively. Soil organic matter (Walkley, 1947), Extractable K (Rhodes, 1982) while soil available P was determined by (Watanabe and Olsen, 1965) and soil texture by Bouyoucus method (Gee and Bauder, 1986). Soil moisture contents were determined by gravimetric method (American Society of Agronomy, 1965). All laboratory determinations were carried out at Soil and Water Conservation Research Station, Fateh Jang.

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
7.81	0.87	0.66	2.33	43.0	22.0	Sandy Loam

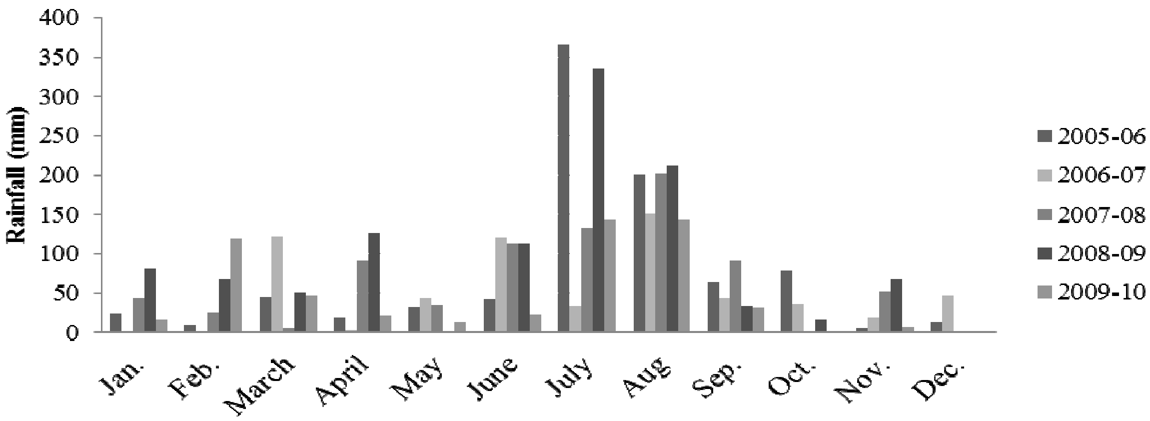
Crop Data

At the end of each growing season, plots were manually harvested, one m^2 sample of wheat was collected and dry grain yield was determined.

Rainfall

Rainfall (mm) was recorded at experimental site (Fig 2).

Fig. 2: Rainfall Distribution at Study Area



Statistical Analysis

The data collected was statistically analyzed using RCBD described by Steel and Torrie (1997). The MS Word & Excel-2010 and M-Stat C computer softwares were used to compare the differences using LSD test.

RESULTS AND DISCUSSION

Performance of LSTS

LSTS were visited regularly after every rainfall event and the following data was recorded for evaluation of their performance:

Displacement of stones

To observe the stability of structure, displacement of stones was monitored after every rainfall during and after the growing season. It was observed that soil sediment and vegetation grown in the stones had strengthened the structures. When ever and where ever, any displaced stone was found, fixed again.

Settlement of stones due to undermining or surface soil loss

It was observed during the study that with the passage of time gaps among the loose stones were filled with soil which then settled the stones. No major damage to these structures was observed during this study. The performance of these structures improved with time as they settled and grasses grew within the structure. 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. The structures harvested adequate runoff, so there was improved soil moisture and positive crop response to fertilizer. As a result, crop yields increased by 20-25% on some farms (Akhtar *et al.,* 2004).

Erosion/gully development at down stream and up stream of the LSTS

The major success of these structures was that they greatly minimized the erosion and gully development at upstream and downstream due to run off. Structures had safely disposed the surplus rain water. However, minor rills found at downstream were repaired. The stone act as a filter for coarse sediment during major rainfall events (Nyssen *et al.,* 2000). Nasri *et al.* (2004) reported that well maintained water harvesting systems are able to infiltrate all runoff.

Hydrological/drainage performance of LSTS

Height of water passed over the crest of the structure, was also measured to asses its drainage and disposal performance. Soil erosion rates are partially controlled by soil and water conservation structures such as stone bunds (Table 2).

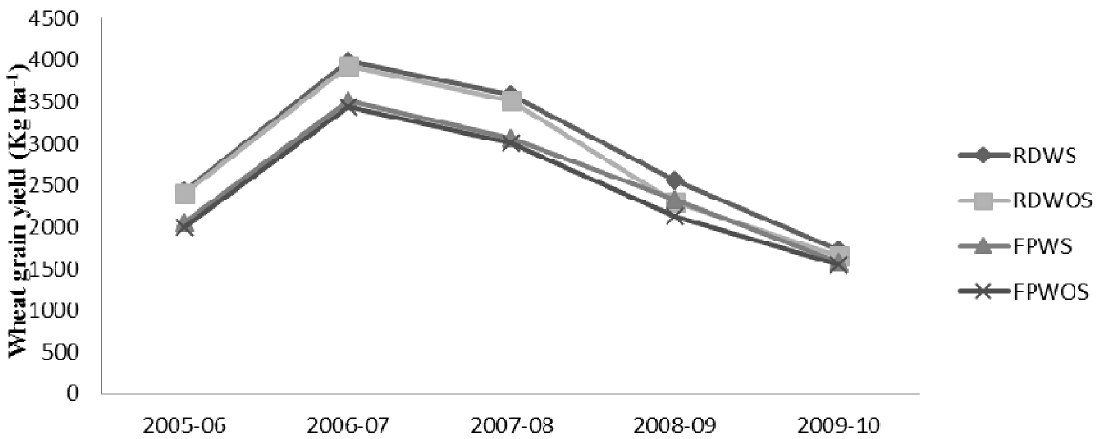
Table 2: Effect of the highest rainfall event on LSTS

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)
2006	7	409	68	4.00-7.25
2007	5	766	42	3.25-4.50
2008	9	439	94	3.00-6.50
2009	4	329	42	1.50-2.50
2010	9	601	102	0.75-1.50

Crop yield

In-situ soil moisture conservation practices and techniques including LSTS are establish to improve the productivity of cultivated soils in sloppy lands. Wheat is the most important crop of the area. When the LSTS were tested in terms of their response to wheat production, results were encouraging and it was noticed that LSTS improved the crop yield considerably (Fig. 3). The maximum crop yield (3994 Kg ha^{-1}) was recorded in 2006-07 in RDWS. It was 12 % higher than FPWS same year. Almost the same trend was noticed in every year. Overall, during five years (2005-10) it was observed that RDWS increased the wheat yield 3.5 % compared to RDWOS, 12.2 % compared to FPWS and 15.1 % compared to FPWOS which revealed a significant increase in wheat yield by LSTS. The response was best and evident in RDWS which may be attributed to lower fertilizer inputs use in the study area along with soil and water erosion losses. The increase in the crop yield was not directly related to rainfall. In some cases when rainfall was higher crop yield was reduced which may be the result of weeds infestation. Further more, these lands are prone to run off and erosion and the LSTS might have minimized the magnitude of soil erosion losses and soil fertility depletion through run off since LSTS provide more time for water infiltration. Soil moisture conservation practices could also be used for restoration of the productivity of such lands which suffers from moisture shortage (Prinz *et al.,* 1996). The potential short-term benefits of stone bunds are the reduction of slope length and the creation of small retention basins for runoff and sediment (Bosshart, 1997). They therefore reduce the volume and erosivity of the overland flow. These effects appear immediately after the construction of the stone bunds and result in reduced soil loss. In the long term, slow-forming 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 described by Vancampenhout *et al.* (2003). Elamin (2010) investigated that the water harvesting techniques significantly increased the storage capacity of the soil for water which significantly increased the grain yield by 43%. Alemayehu *et al.* (2006) in his study indicated that indigenous stone bunding has a positive effect on crop yield. Related experimental study of Zougmore *et al.* (2002) showed that stone lines, five years after lying, have a limited effect on soil fertility and crop productivity. The explanation by Shemdoen *et al.* (2009) confirms that evaluating soil fertility by crop yield alone is not fair because crop performance is a function of many factors including soil nutrient (fertility) itself, soil water availability, and weed competition. On eroded soils yield can be improved by balanced application of fertilizers (Izaurralde *et al*., 2006).

Fig. 3: Effect of FWCS on wheat grain yield



Soil Characteristics

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 been leading to soil erosion and nutrient depletion thereby escalating the risk of land degradation. Indeed, the farmers use local practices, which include manure application and a mixture of agronomic practices to combat soil degradation and improve productivity. High fertilizer cost is often mentioned as major impediments to local initiatives. Significant differences were noticed in the soil properties (Fig. 4, 5, 6 and 7). Runoff causes erosion of fertile topsoil, resulting in soil degradation (Schiettecatte *et al.,* 2005). Nutrient indexing survey of wheat in *Pothowar* 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).

Organic Matter

LSTS revealed a significant effect on soil organic matter never the less soil and water conservation practices require long time to mark any serious impact because soil and water erosion and run off did not allow to develop soil structure and sweeps away all the top soil. Data (Fig. 4) recorded showed that on average maximum (0.85%) organic matter content was recorded in RDWS followed by 0.81% in FPWS while the lowest organic matter content (0.77%) was estimated in FPWOS. Holechek *et al.,* (1989) reported that in dry land the effect of soil and water conservation management takes a long time to be appreciated. Khan *et al.* (2003) observed decrease in O.M. with increase of erosion. 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 Pothowar plateau (Rashid and Qayyum, 1990).

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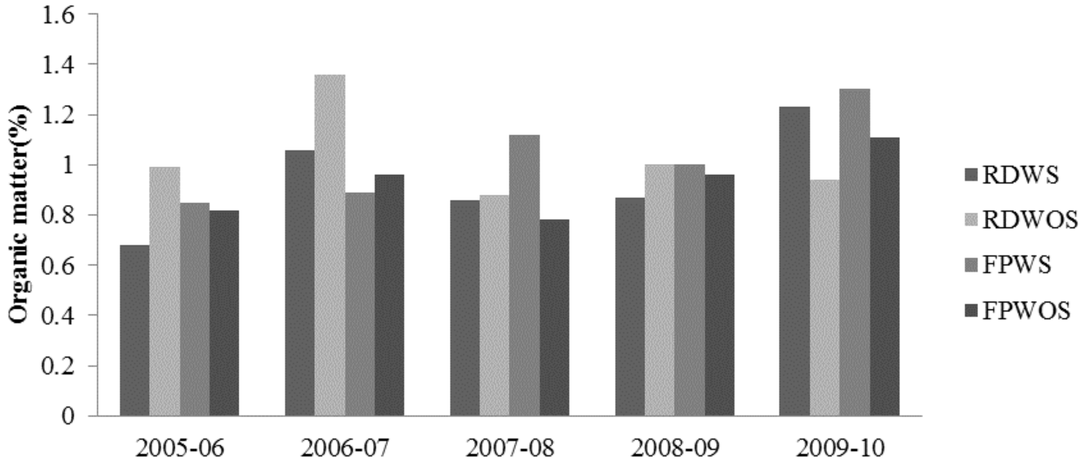
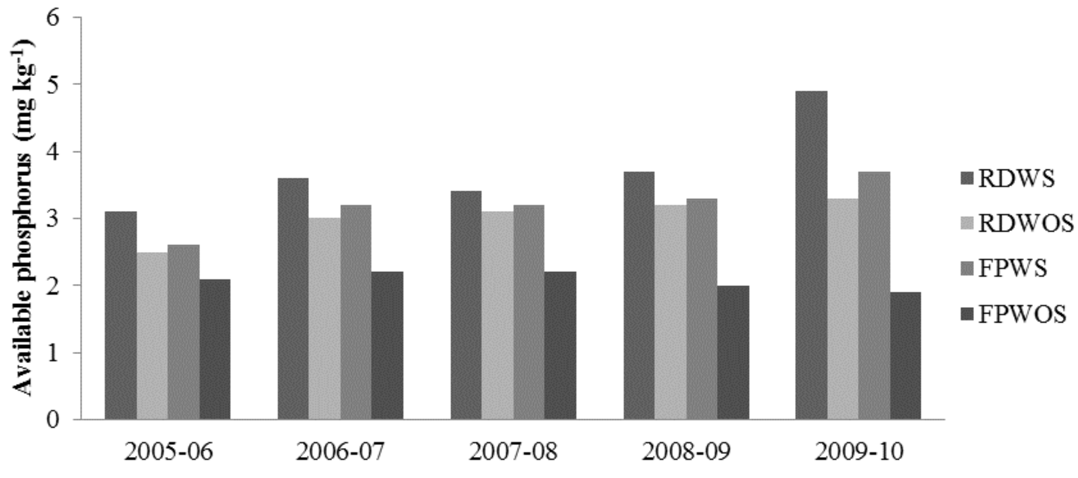
Fig. 4: Effect of LSTS on organic matter



Available Phosphorus

The average available phosphorus values of both structured and the non-structured soils were recorded and found that by adopting LSTS soil phosphorus (Fig. 5) was enhanced from 3.1 to 4.9 mg kg^{-1} in RDWS during 2005-2010. On average phosphorus was in order of RDWS > FPWS > RDWOS > FPWOS. Almost the similar behavior was noticed in all treatments every year. This might be attributed to availability of higher soil moisture and reduced run off which might have increased the availability of soil Olsen P through mineralization. Glendinning (2000) revealed 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 LSTS 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_2O_5 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 land. Gete (2000) also studied that erosion can lead to the removal of available phosphorus including other nutrients from the top soil. The soils of Paksitan 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 (Chaudry *et al*., 2007).

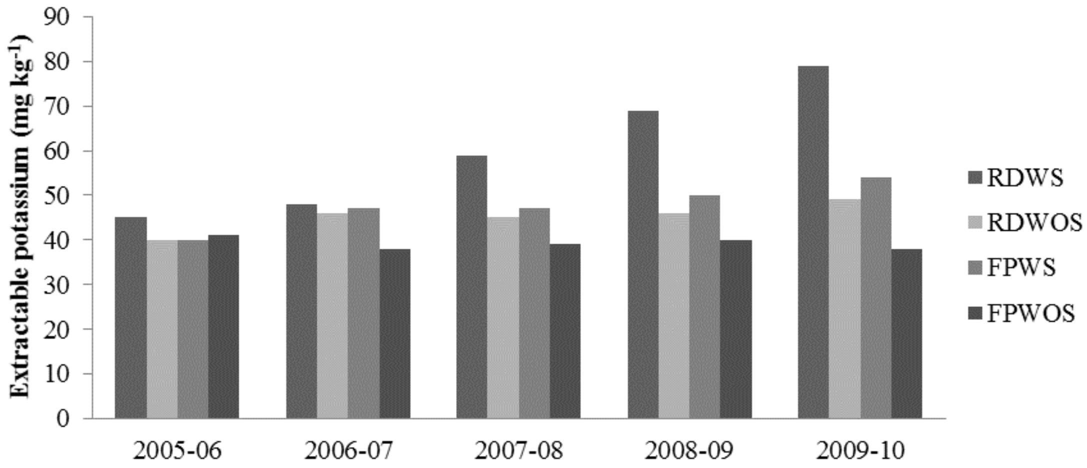
Fig. 5: Effect of LSTS on soil phosphorus



Extractable Potassium

The average extractable potassium content (Fig. 6) of both the structured and without structured was recorded and revealed that with the passing time and by LSTS soil K level was increased at structured soils and particularly in RDWS from 45 to 79 mg kg^{-1}. But, run off in non structured soil has decreased the K level (41 to 38 mg kg^{-1}) in FPWOS due to enhanced erosion which could be lead to fertility depletion. In-situ water conservation practices have long been utilized as a measure to reduce soil erosion and sedimentation and to increase soil water storage and soil fertility (Xiao-yan *et al.,* 2004). 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. Soil and water conservation practices reducing the negative effect of intense rainfall, resulting in a lower amount of runoff and erosion and significantly increasing the amount of soil organic matter, Mg, Ca, and K (Abu Hammad *et al.,* 2006). SWC structures are practically used as support for agronomic and soil management (Morgan *et al.,* 2005) and considered as the first defense line. Thus, they alone are less likely to improve soil properties significantly.

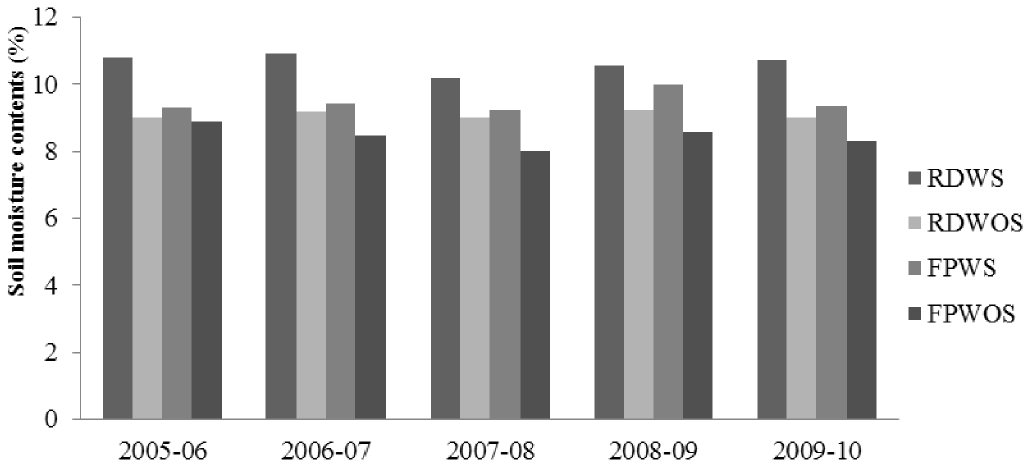
Fig. 6: Effect of LSTS on soil potassium



Soil Moisture

LSTS has significantly enhanced the soil moisture contents (Fig. 7) which was the major concern of the famer community and the main objective of this study. Results revealed that the gravimetric soil moisture contents were improved significantly (13%) in structured soils and especially in RDWS every year. Five year data revealed that average maximum moisture contents (10.63%) were recorded in RDWS which were 14.49% higher than RDWOS and 11.00% more compared to FPWS where as 20.61% higher in FPWOS. Vancampenhout (2003) found that stone bunds enhance soil moisture storage on both sides of the bund, especially on loamy and sandy soils. (Hudson, 1987; Schwab *et al.,* 1993) in a study revealed increase in soil moisture in upper decimeters 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). Temporal changes and variability of soil moisture are affected and controlled by topography, soil types, vegetation, land use and management practices (Fu *et al.,* 2003). Soil management reduced the surface runoff which had accelerated infiltration and consequently increased soil moisture stored in the soil profile. A similar result were observed by other researchers (Al-Kharabsheh 2004; Mugabe 2004) found that water and soil management practices, such as stone terraces, ridges and furrows, significantly increased soil moisture storage over that in untreated areas. Stone bunds enhance soil moisture storage on both sides of the bund, especially on loamy and sandy soils (Nyssen *et al.,* 2000). To store more rainwater and to make it available for plant uptake, erosion control and soil fertility improvements are needed (Rockstrom and Falkenmark, 2000).

Fig. 7: Effect of LSTS on soil moisture



CONCLUSIONS AND RECOMMENDATIONS

LSTS improved the crop yield up to 15 %. Soil characteristics were also improved for crop cultivation and profile soil moisture contents were enhanced up to 21%. A considerable decrease in gully development and soil sediment loss was observed by reduction in run off and in-situ soil moisture conservation.

On the basis of observations and results of this study farmers are strongly recommended to adopt integrated nutrient management practices along with soil and water conservation measures because the fruits of these efforts need time and conveyed that cheap and locally feasible soil and water conservation measures like LSTS are desperate to protect their lands from deterioration and degradation.

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