Restoring the Land Productivity of Eroded Land through Soil Water Conservation and Improved Fertilizer Application on Pothwar plateau in Punjab Province, Pakistan

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Abstract: Crop production in a rainfed area is constrained by inappropriate management of soil and water by the resource-poor farmers. The present study addresses this issue through integration of practices for soil water conservation (SWC) and soil fertility enhancement as well. Extensive experimentation on wheat-maize was undertaken for two years (2004−2006) on the fields of eight farmers representing two soil types; Rajar (Typic Ustorthent; USDA soil taxonomy) and Guliana (Udic Haplustalf; USDA soil taxonomy) in the Gujar Khan Tehsil of Rawalpindi District, Pakistan. Four treatments consisting of: no SWC+farmer’s rate of fertilizer application (FP), no SWC + improved fertilizer application (IF), SWC practices i.e., deep plowing, bund improvement, plowing across contour + FP (SWC+FP) and SWC+IF. Wheat and maize grain yields in SWC and IF were statistically higher than in the treatments with no SWC and FP, respectively. Compared with the control without any treatment, increase in water use efficiency of both maize and wheat crop was higher in SWC+IF followed by IF alone. On the average, Guliana soil series showed better response to all treatments than Rajar soil. The integrated application of SWC and IF practices increased crop yields in the rainfed area.

Key words: Inorganic fertilizer application, Maize and wheat yield, Soil erosion, Soil and water conservation practices.

The Pothwar plateau (latitude 32º10’ to 34º9’N and longitude 71º10’ to 73º55’E) is an important part of the rainfed zone of Pakistan and covers an area of 1.8 million hectares. Rainfall is irregular and 60−70% of rainfall is received during the monsoon rainy season i.e. mid June to mid September. The plateau generally has a flat to gently undulating surface, soil erosion by water, viz sheet, rill and gully erosion is common (Nizami et al., 2004). Soils of Pothwar consist of loess material, and there is more surface crusting due to the high proportion of fine silt and clay. These soils also have a plough pan and at places fragipan which reduces the water intake rate and hinders root penetration (Shafiq et al., 2005).

Low productivity of rainfed crops is mainly attributed to low soil fertility and soil moisture stress due to more rainwater loss by erosion. Soil fertility is reduced when clay and organic materials are removed with rain water (Sen, 2003).

In rainfed areas due to multiple nutrient deficiencies there is nutrient imbalance (NFDC, 2000). The imbalance use of fertilizers further enhances nutrient deficiencies. Alkaline and calcareous nature of soils also induces low availability of micronutrients (Shorrocks, 1997).

Soil nutrient management and SWC practices are precondition to augment crop yield in rain fed tract. Practice of deep tillage before onset of rainy season capture and retain precipitation in soil. Chiseling penetrate soil depths ranging from 20−30 cm (Ngigi, 2003), which break the hard pan, increase soil moisture storage and reduce runoff (Vaughan et al., 2000). Shafiq (2007) reported that in Pothwar area about 50% of the farmers practice deep ploughing before monsoon (rainy) season. However, they do not adopt other SWC practices like land terracing, improvement of field bunds and contour plough. Therefore, deep ploughing may not be enough effective for rainwater conservation and soil fertility improvement.

The correction of a nutrient imbalance increases crop yield. Izaurralde et al. (2006) stated that application of N and P fertilizers and manure improved grain yield and reduced the yield loss due to erosion. The benefits of soil conservation were more where soil fertility improvement was incorporated. Water conservation practices with 180 kg
Table 1. Soil characteristics of experimental fields.

| Soil characteristics | Rajar soil series (cm) | Guliana soil series (cm) |
|----------------------|------------------------|-------------------------|
| pH _{H_2O} | 7.84±0.17 7.95±0.05 | 7.84±0.13 7.90±0.14 |
| EC_{a(1:5)} dS m^{-1} | 0.44±0.36 0.20±0.08 | 0.25±0.05 0.23±0.04 |
| Organic matter | 0.82±0.09 0.51±0.19 | 0.96±0.13 0.70±0.06 |
| CaCO_3 | 6.28±4.89 7.52±3.82 | 2.63±2.18 4.11±5.95 |
| Nitrate-N | 2.85±0.57 2.41±2.15 | 4.77±3.01 2.03±0.49 |
| Phosphorus | 0.20±0.26 0.32±0.13 | 1.09±0.55 0.09±0.07 |
| Potassium | 80±18 77±13 | 96±14 72±15 |
| Copper | 2.71±0.42 3.36±0.93 | 2.76±0.38 2.15±0.20 |
| Iron | 4.81±0.32 3.64±1.89 | 3.94±1.04 3.32±0.69 |
| Manganese | 5.46±1.24 4.32±2.79 | 4.43±0.54 2.63±0.59 |
| Zinc | 0.28±0.05 0.19±0.75 | 0.62±0.32 0.22±0.06 |
| Boron | 0.21±0.17 0.04±0.02 | 0.50±0.33 0.22±0.17 |
| Soil texture | Silt Loam | Silty Clay Loam |
| Geomorphology | Loess Plain | Loess Plain |
| Landform | Very severely dissected | Slightly eroded Loess Plains |

± Standard deviation of the mean.

N ha⁻¹ increased WUE significantly (Sepaskhah and Hosseini, 2008). Erosion control and soil fertility management practices are needed to conserve rainwater for plant uptake (Vancampenhout et al., 2006). The agriculture in a rainfed field depends on water availability through rainfall. Management of soil and water at an appropriate time plays a significant role in crop production. The objective of the present study was to evaluate the effect of integrated SWC and fertility management practices on crop production on eroded lands.

Materials and Methods

1. Study sites

The study was conducted at farmers’ fields on the Pothwar plateau in Gujar Khan. The Gujar Khan area lies between latitude 33°–10’ and 33°–15’ N and between longitude 73°–15’ and 73°–20’ E. It is semi-arid during winter season and sub-humid during summer season. Sixty to 70% of the rainfall is received during the rainy season viz. mid June to mid September. The total precipitation received during the wheat cultivation in 2004–2005 was 515 mm, which was received in 23 rainfall events. During the wheat cultivation period in 2005–2006, it was only 136 mm, and was received in 7 rainfall events. The precipitation received during the maize cultivation in 2005 was 306 mm in 14 rainfall events and that in 2006 was 550 mm in 18 rainfall events. The physical and chemical properties of the soil in the study site are listed in Table 1.

2. Experimental design and treatments

The experiment was conducted in randomized complete block design (RCBD) with four replications for each treatment. Eight fields/sites (farmers’ field) were selected; four fields had the Rajar soil type (Typic Ustorthent; severely eroded; 3–4% slope) and four fields had the Guliana soil type (Udic Haplustalfs; slightly eroded; 0–1% slope). The size of four Guliana soil fields was 0.08, 0.27, 0.31 and 0.36 ha, and that of Rajar soil fields was 0.08, 0.62, 0.30 and 0.22 ha. Plant nutrients N, P, Zn and B were applied as improved fertilizer application treatment because these nutrients showed alarming deficiency in experimental areas in soil analysis (Table 1). The term improved/balanced fertilizer application in this study means application of deficient nutrients and other fertilizers at recommended rates based on several studies carried out in rainfed area (Shafiq et al., 2003; Jilani et al., 2007; Shaheen et al., 2010). There were four treatments as described below:

- T₁: Fertilizer application according to farmer’s practice viz. 40 kg N ha⁻¹ + 13 kg P ha⁻¹ + No soil water conservation (SWC) (IF)
- T₂: Improved fertilizer application viz. fertilizers were applied at a rate of 100 kg N, 26 kg P, 2 kg Zn and 1 kg B ha⁻¹ + No SWC practices (IF)
- T₃: SWC viz. deep plowing, contouring (ploughing across the slope) and land improvement + FP (SWC + FP)
- T₄: SWC + IF (SWC + IF)

3. Crop and soil management

The fertilizers urea and diammonium phosphate (DAP) were applied as the source of N and P, respectively before sowing each crop. In IF treatments 50% N was applied as band placement and 50% as top-dressing. Phosphorus was also applied at the time of sowing by band placement method. The Zn and B as zinc sulfate and borax, respectively, were broadcasted for wheat in 2004–2005 and maize in 2005. In the control, fertilizers were applied according to farmer’s practices; viz. broadcasted both N and P before sowing.

Wheat and maize were grown as winter and summer crops, respectively, in rotation in 2004–2006. The fields were well prepared by ploughing with a tractor-mounted cultivator three times. Before the start of monsoon rainfalls (i.e. mid June to mid September) soil was deep tilled with chisel plough to a depth of 30 cm in all SWC treatments. In this way deep ploughing (chiseling) was done once a year after harvesting the wheat crop and before sowing the maize crop. The wheat variety Bhakhar 2000 was sown at the rate of 100 kg ha⁻¹ using a sowing drill. The maize variety Neelum was sown at a rate of 40 kg ha⁻¹ using a sowing drill. Experiments were conducted on the same fields by adopting the same layout plan. Crops were kept free of weeds by hoeing and weeding by hand, and harvested manually.
4. Sampling and measurements

Plant samples in a quadrate of 1 m² were collected three times from each treatment to obtain yield data and samples of grain and straw/stover. No crop residues were left on the ground after harvesting each crop. After harvesting, the crop was bundled separately for each treatment and grains were threshed with a tractor-mounted thresher.

5. Soil analysis

Composite soil samples were collected from selected experimental fields from top soil (0−15 cm) and sub-soil (30−45 cm) layers. Pre-sowing soil was analyzed for texture, pH, EC, CaCO₃, organic matter, NO₃-N, P, K, Zn, Cu, Fe, and Mn, and extractable B. The protocol for each laboratory analysis was as follows: The particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH was measured with a glass electrode and EC was determined with an EC meter in a suspension of soil to water ratio of 1:1 (McLean, 1982). The CaCO₃ contents were determined by titrating digested sample with NaOH (Soltanpour and Workman, 1981). Soil organic matter was determined by digesting soil with 1 N K₂Cr₂O₇ and H₂SO₄, and then titrating the digest against 0.5 N FeSO₄.7H₂O (Nelson and Sommers, 1982). For determination of NO₃-N, P, K, Cu, Fe, Mn and Zn, soil was extracted with AB-DTPA solution and the extracted aliquot was stored in clean plastic bottles (Soltanpour and Workman, 1979). For estimation of NO₃-N, absorbance of light in the extract was read at 540-nm wavelength on spectrophotometer (Rashid et al., 1994). Results are given in Table 1.

Water use efficiency (WUE) was calculated as follows:

\[
\text{WUE (kg ha}^{-1}\text{mm}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total water supplied (mm)}}
\]

Soil water contents were measured gravimetrically at planting and after harvest of each crop up to 90 cm depth. Crop water use was calculated as:

\[
\text{Total water supplied (mm)} = \text{Water at planting−Water at harvest} + \text{Precipitation in growing season}
\]

6. Statistical analysis

Data collected for various crop attributes were subjected to two-way analysis of variance for statistically significant differences by using M-STAT C software (Freed et al., 1991). Statistical differences among treatments were determined with least significant difference test at 0.05 and 0.01 probability levels according to statistical procedures described by Steel et al. (1997).

Results

1. Crop yields

Employing the practice of IF with or without SWC (SWC+IF) or IF produced a significantly higher wheat grain yield compared with the farmers’ practices (FP) alone or SWC+FP in both years (Table 2). Combined application of SWC and IF did not show any significant yield difference from that of IF. Wheat straw yield in 2004−2005 with SWC+IF had no statistically significant difference from that with other treatments. While straw yield of wheat in 2005−2006 was statistically lower in FP as than in the other three treatments, which did not mutually differ significantly. Guliana soil produced statistically
higher wheat grain and straw yields than Rajar soil in 2004–2005, while wheat in 2005–2006 did not show any significant difference between the two soil types. In 2004–2005, significantly higher grain and straw yields were produced than in 2005–2006. Statistical analysis indicated that interaction of year × soil (Y × S) was significant while interactions of year × treatment (Y × T), S × T and Y × S × T were not significant for both straw and grain yields.

Maize yield as influenced by different treatments is shown in Table 3. Statistically higher grain yield was attained by SWC + IF followed by IF. The lowest yield was obtained with FP. The order of grain yield obtained was SWC + IF > IF > SWC + FP > FP. Stover yield of maize in 2005 in SWC + IF was statistically higher, followed by both IF and SWC + FP. Stover yield of maize in 2006 was statistically similar to that with IF. Significantly higher grain and stover yields were obtained in Guliana soil than in Rajar soil except for stover yield of maize in 2005 which showed no significant difference between the two soils. There was no statistical difference in grain production between the two years (2005 and 2006) while stover yield was higher in 2006 than in 2005. The results of statistical analysis showed that interactions Y × S, S × T, Y × T and Y × S × T were not significant for both straw and grain yields.

2. Water use efficiency

Mean values of WUE of wheat and maize crops (Table 4) in both years indicated that the increase in WUE was statistically higher in SWC + IF followed by IF and SWC + FP as compared with FP. In wheat in 2004–2005, WUE with SWC + IF and IF was statistically similar; while in wheat in 2005–2006 and in maize in both years, SWC + IF gave significantly higher WUE than IF. Thus, integrated application of SWC and IF produced higher yields per unit water consumed. The plants on Guliana soil had more WUE than those on Rajar soil. Statistical analysis showed that interactions Y × S, S × T, Y × T and Y × S × T were significant for both crops. This shows that the amount of rainfall received during the crop season also has a significant effect along with fertilization and water conservation practices on crop production.

Discussion

In rainfed agriculture, optimum nutrient supply and soil moisture availability are important for higher crop production. Importance of fertilizer application to maximize the use efficiency of stored water in root zone has long been recognized (Cai et al., 2002). In the present study, wheat yield under low fertilizer farmers’ practice (FP) was significantly increased by SWC in the dry-year crop (2005–2006). The absence of a significant difference between IF and SWC + IF could be due to the balanced/improved fertilization (application of all the deficient nutrients), which helped utilize the soil moisture efficiently. Therefore, under reduced and imbalanced fertilization, the significance of SWC is further increased. Yang et al. (2004) reported that by balanced fertilizer application, straw yield of wheat was increased 148%. Ali (1998) observed that the yield and water use efficiency of wheat were significantly improved by deep tillage because of better moisture availability. The greater infiltration and storage of water in soil is attributed to the deep tillage before the intense summer rains. Subsoiling enhances the uptake of water by crops from the deep soil layers (Izumi et al., 2009).

SWC with either IF or FP improved maize grain yield significantly. The difference between the response of wheat and maize to SWC was due to the requirement of less water in wheat. The amount of rainfall played a significant role in crop production. Statistically higher wheat yield in 2004–2005 than in 2005–2006 was entirely due to

| Treatments                        | 2005     | 2006     | 2005     | 2006     |
|-----------------------------------|----------|----------|----------|----------|
| Farmers’ practices (FP)            | 1.70 ± 0.26 d | 1.78 ± 0.61 c | 5.22 ± 0.82 c | 5.46 ± 0.54 c |
| Improved fertilizer application (IF)| 3.23 ± 0.62 b | 3.35 ± 0.69 b | 6.22 ± 1.01 b | 7.44 ± 0.58 a |
| Soil water conservation + FP      | 2.29 ± 0.26 c | 2.36 ± 0.68 c | 5.98 ± 0.64 bc | 6.55 ± 0.44 b |
| Soil water conservation + IF      | 4.20 ± 0.81 a | 3.99 ± 1.13 a | 7.09 ± 0.79 a | 7.73 ± 0.59 a |
| LSD                               | 0.38     | 0.61     | 0.89     | 0.58     |

| Soil series | Grain yield | Stover yield |
|-------------|-------------|--------------|
| Guliana     | 3.15 ± 0.19 a | 3.08 ± 0.99 a |
| Rajar       | 2.56 ± 0.26 b | 2.67 ± 0.39 b |
| Year (Y)    | 2.85 ns      | 2.87         |

Means in a column/row followed by same letter(s) are statistically non-significant at P ≤ 0.05.
ns = Non-significant difference among interactions at P ≤ 0.05.
± Standard deviation of the mean.
may be attributed to their erosion class. Guliana soil is a slightly eroded soil, while Rajar is a severely eroded soil. Organic matter, nutrient contents and clay percentage (that retains nutrients) in Guliana soils were higher than in Rajar. Further, Guliana soil contains less CaCO3 than Rajar soil, the nutrient availability was higher in Guliana than in Rajar soil. Erosion reduces the soil nutrient availability, water holding capacity, infiltration rate and crop yields (Haileslassie et al., 2005). By adopting soil management and water conservation practices the adverse effect of erosion can be mitigated. Fenton et al. (2005) reported that reduction of corn yields in severely eroded soils averaged 23% as compared with slightly eroded soils. In rainfed regions, rainfall is very important parameter of agricultural production. It is not only the amount, but also the distribution and intensity of rainfall. Significantly low wheat yield recorded in 2005−2006 was due to the dry period, but even in this year, a good yield was obtained under SWC practice as compared with that without SWC. This indicated that soil management and water conservation are important for enhancing crop yields in rainfed areas (Walker and Schulze, 2006). Balanced fertilization is still crucial for higher crop yields. Low fertilizer rates and application of only macronutrient fertilizers by the farmers limit crop production due to nutrient shortage.

**Conclusion**

Integrated soil water conservation and improved fertilization (SWC+IF) gave a statistically higher maize yield over other practices. In wheat crop, SWC+IF and IF did not show a statistically different yield but gave a higher yield than FP or SWC+FP. This suggests that soil management and water conservation practices (land improvement, deep ploughing and fertility management etc.) in erosion-vulnerable rainfed areas will be helpful to

### Table 4. Effect of integrated fertilizer application and soil water conservation on WUE (kg ha⁻¹ mm⁻¹) of wheat and maize.

| Treatments                | Wheat 2004−2005 | Wheat 2005−2006 | Wheat 2005 | Wheat 2006 | Maize 2005 | Maize 2006 |
|---------------------------|-----------------|-----------------|-------------|-------------|-------------|-------------|
| Farmers’ practices (FP)   | 6.08±1.66 c     | 2.55±0.29 d     | 4.70±0.31 d | 3.35±0.43 d |             |             |
| Improved fertilizer application (IF) | 7.33±1.56 a | 4.64±0.24 b     | 8.75±1.89 b | 5.35±0.47 b |             |             |
| Soil water conservation + FP | 6.44±1.50 b | 4.02±0.12 c     | 6.35±0.82 c | 6.35±0.30 c |             |             |
| Soil water conservation + IF | 7.41±1.41 a | 5.43±0.38 a     | 11.56±2.19 a| 10.80±0.87 a|             |             |
| LSD                       | 0.22            | 0.20            | 0.27        | 0.21        |             |             |
| Soil series               |                 |                 |             |             |             |             |
| Guliana                   | 8.24±0.09 a     | 4.31±0.07 a     | 9.03±0.11 a | 7.99±0.10 a |             |             |
| Rajar                     | 5.39±0.12 b     | 4.00±0.12 b     | 6.66±0.08 b | 7.10±0.09 b |             |             |
| Year (Y)                  | 6.81 a          | 4.16 b          | 7.84 ns     | 7.55        |             |             |

Means in a column / row followed by same letter (s) are statistically non-significant at P ≤ 0.05.

ns = Non-significant difference among interactions at P ≤ 0.05.

± Standard deviation of the mean.

Abundant rainfall in 2004−2005 (515 mm) and very little rain in 2005−2006 (136 mm). Precipitation received during maize cultivation in 2005 was 306 mm and that in 2006 was 550 mm. The larger amount of rain in 2006 caused statistically higher stover biomass of maize than in 2005. The absence of a significant difference between maize grain yields between the two years could be due to the availability of enough water for normal crop production.

Furthermore, the high maize yield under SWC+IF was the result of sufficient availability of both water and nutrients to the crop. Similarly, high yields under SWC+IF and IF compared to that in SWC+FP and FP are attributed to balanced / improved fertilization in IF treatments. Here, integrated use of deficient nutrients (N, P, Zn and B) in the respective fields gave higher crop yields as compared with FP plots where only N and P were applied even at lower rates. Iqbal et al. (2005) reported that higher grain yield of wheat was obtained with tillage and NP fertilizers. Therefore, proper SWC+IF can ensure higher crop yields in rainfed areas (Shafiq et al., 2003).

Intensive nutrient uptake by the crops and insufficient nutrients input through fertilizers are among the major constraints related to declining crop yields in Pothwar region (Jilani et al., 2007). The soil with adequate fertility can help crop plants better utilize the available soil water. Under a low soil water potential, the efficiency of plants to absorb nutrients and capacity of soil to supply them are reduced. Thus both SWC+IF increase WUE. Deficiency of any essential nutrients results in yield reduction and it lowers WUE. Balanced nutrient supply increases the size of crop canopy that improves shading on the soil surface. Thus larger crop canopies may reduce the soil water evaporation and increase the amount of available water for transpiration resulting in improved WUE of the crop.

Higher yields obtained on Guliana soil than on Rajar may be attributed to their erosion class. Guliana soil is a slightly eroded soil, while Rajar is a severely eroded soil. Organic matter, nutrient contents and clay percentage (that retains nutrients) in Guliana soils were higher than in Rajar. Further, Guliana soil contains less CaCO3 than Rajar soil, the nutrient availability was higher in Guliana than in Rajar soil. Erosion reduces the soil nutrient availability, water holding capacity, infiltration rate and crop yields (Haileslassie et al., 2005). By adopting soil management and water conservation practices the adverse effect of erosion can be mitigated. Fenton et al. (2005) reported that reduction of corn yields in severely eroded soils averaged 23% as compared with slightly eroded soils.

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control soil fertility degradation, and they will ultimately increase the crop yields. The increase in WUE was mainly caused by the establishment of water conservation measures and improved fertilizer application. Fertilizers have a great potential to further increase the WUE in the rainfed area of Pothwar plateau, especially for the crops grown in summer after rainy season when the water supply is plentiful.

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