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Cereal-legume intercropping

for managing erosion in arid soil

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Kachchh district in Gujarat is mostly known for soil salinity with presence of two large salty marshlands, i.e. the Great and the Little Rann. However, the fact is that the lands in Kachchh are mainly degraded due to soil erosion under the changing climate, and salinity counts afterwards. Erosion of soil further results in loss of nutrients from the fertile top soil, and thus, declining crop productivity. Cultivation of sole cereal crops is a common practice in the region, which results in huge amount of soil and nutrient losses from limited soil depths. Legume crops like green gram and cluster bean may be suitably intercropped with cereal crops of sorghum and pearl millet in 2:1 cereal-legume row ratio to check soil loss and conserve soil nutrients.

Keywords: Acid soil, Lime, NEH region, Nutrient deficiency, Organic manures

DEGRADATION of soil occurs over a long period of time due to continuous decline in soil productivity and its environment moderating capacity. About 120.72 million ha area in India is under land degradation, and water erosion causes 68% of the land degradation. The soil erosion process removes fertile topsoil, which reduces crop yields up to 60% in different soil types of the country. Thus, soil erosion not only has a debilitating effect on crop productivity but also on socio-economics of farming communities. In intensive agricultural systems, soil erosion has detrimental effects on soil quality and crop yields owing to: (i) restricted water storage capacity of the soil, (ii) impeded water availability to plants, (iii) reduced nutrient supply to plants, and (iv) limited plant-rooting space.

Arid lands in Gujarat suffer from degradation mainly due to water erosion in 43% area followed by salinity, vegetation degradation and wind erosion in 38%, 10% and 5% area, respectively. Kachchh, the second largest district of the country, is situated in the arid region of Gujarat, where water erosion is the most dominating land degradation process. The impact of water erosion is very severe in 17.1% area of the Kachchh district, severe in 9.9% and moderate in 5.2% area. Loss of crop yields due to water erosion may be small if sufficient soil depth is available as the nutrient losses may be appropriately counterbalanced by adding increased fertilizers. On the other hand, significantly high yield loss may occur in areas having limited soil depths. In the Kachchh district, soil depth is shallow over most of the land areas, and thus, large amounts of soil particles and nutrients are lost through soil erosion. The process of soil erosion involves detachment and transportation of top soil from agricultural lands. The top soil is very fertile due to the presence of minerals and nutrients, and hence, erosion also results in the loss of nutrients from the soil leading to a reduction in crop productivity. On top of it, climate change and variability are causing a considerable increase in rainfall intensity, which results in huge rainwater received in a short duration in the area. Thus, it is imperative to adopt suitable practices for preventing loss of soil particles and nutrients from agricultural lands in order to protect crop yields in the arid region of Gujarat.

Agronomic practices such as mulching and intercropping are found effective in controlling soil erosion mostly in humid and semi-arid regions. In arid regions, rainstorms have fewer occurrences and that too in low amounts compared to other regions. Hence, it is difficult to monitor soil and nutrient losses accurately and to find the efficacy of agronomic practices in checking soil erosion. Therefore, this study aimed at developing a cost-effective experimental setup, runoff and soil sampling, monitoring soil and water parameters, laboratory testing and analyses to find the effectiveness of cereal-legume intercropping in preventing soil and nutrient losses in Kachchh, Gujarat.

Low-cost design and construction of Multi-slot Divisor

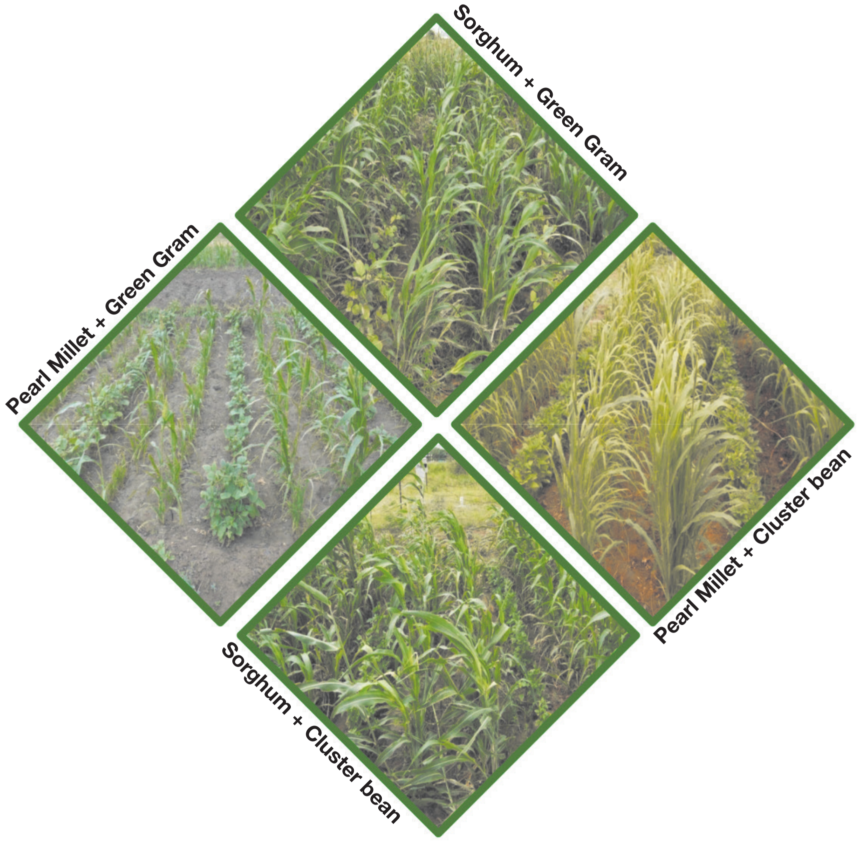
Multi-slot divisor is a standard device to collect runoff and soil loss samples under field conditions. A multi-slot divisor was designed considering the local settings of the area including the maximum rainfall intensity during the last 10-year period and a high value of runoff coefficient as 0.30 for sandy soils of the area in estimating the peak daily runoff. Prior to finalizing the design of the multi-slot divisor, a large range of specifications, i.e. length, height, number of slots and slot diameter, and size of the runoff collection tank, shapes and variety of construction materials, i.e. galvanized iron and mild steel for the multi-slot divisor were considered to make low-cost divisor with ease of fabrication under the locally available facilities. A length of 1.8 m and a height of 0.60 m were finalized for the divisor depending on the standard specifications of mild steel sheet available in the market. Likewise, slots of only 2.54 cm diameter were drilled in the multi-slot divisor depending upon the locally available hole-drilling facility in the area. Then, a number of slots were decided based on the safe disposal of excess runoff from the area. Finally, a multi-slot divisor containing 17 slots of 2.54 cm diameter with 7.5 cm space between two slots costs about ₹2500.

Cereals, legumes and their intercropping

The relative efficacy of sole cereals and legumes and their intercropping practices in checking soil and nutrient losses was evaluated. Two major cereals (sorghum and pearl millet) and two legumes (green gram and cluster bean) were considered. In addition, both legumes were intercropped with sorghum and pearl millet. In total, 8 treatments, viz. : T1-sorghum (S), T2-pearl millet (PM), T3-greengram (GG), T4-cluster bean (CB), T5-intercropping of S+GG, T6-intercropping of S+CB, T7-intercropping of PM+GG, and T8-intercropping of PM+CB were considered. The experimental setup was laid in a randomised block design with three replications and 2:1 row ratio for cereal-legume intercropping.

Setup for runoff and soil sampling

In total, there were 24 plots (8 treatments × 3 replications) of 20 m × 5 m size. The size of 100 m^2 had the recommendation by the Food and Agriculture Organization (FAO) of the United States, Rome for easy computations. Earthen bunds of 30 cm in height were formed surrounding every plot to avoid the flow of runoff water from one plot to another and to direct the generated runoff towards the outlet of the plot. A 2 m alley space was kept between two plots for easy accessibility and to avoid any disturbances within the plots. Multi-slot divisors were fixed at the outlet of 24 plots during 2013. The 1.8 m wide divisors were placed at the middle position on the 5 m wide plot side and bunds were formed on the rest 1.6 m width on each side of the divisor to anchor the divisor at the outlet and to ensure runoff escape through the divisor only. Of the total 0.60 m height of the divisor, about 0.45 m was placed inside the soil surface and the top 0.15 m remained above the surface with slots. A total of 24 used plastic tanks of 50 litres capacity were acquired from the local market at a cheaper cost, which were installed inside the soil surface and connected to slots of multislot divisor for collecting runoff and soil loss samples.



Field views of four cereal-legume intercropping systems

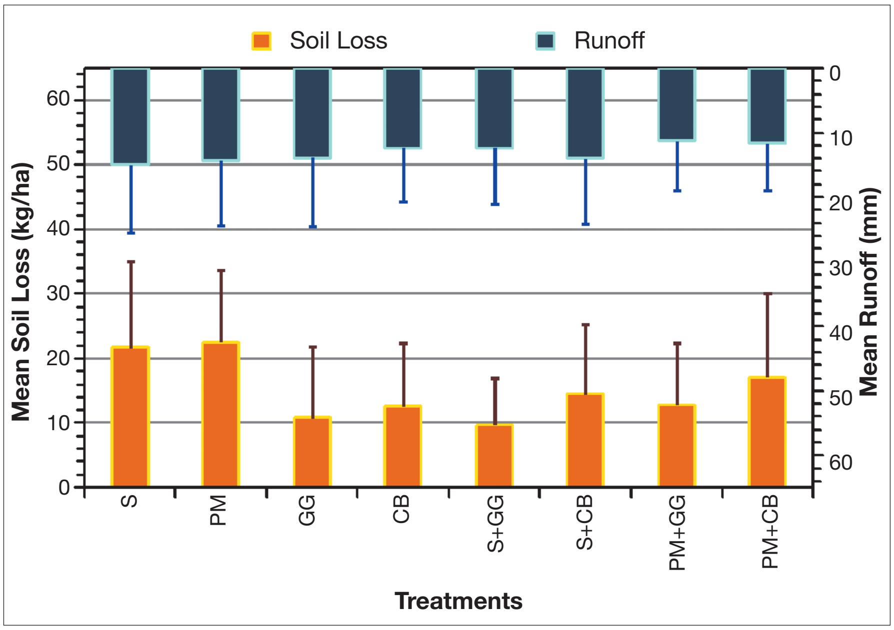
Monitoring of rainfall and runoff

Rainfall on a daily basis was measured with nearest to 1 mm accuracy using a non-recording rain gauge installed at the experimental site. Rainfall occurrences were very rare in the area due to the arid climate, and many times rainfall amount was so less that no runoff was generated inside the agricultural fields. Thus, runoff and soil loss were monitored only for those rainstorms that could make runoff water flow in the experimental plots. Depth of water inside the runoff collection tank was recorded for every plot using a scale after the occurrence of every runoff-producing rainfall event during the 4-year period, which was later converted to runoff volumes.

During a 4-year period, only a total of 7 runoff-producing rainfall events ranging from 27–95 mm occurred in the area with an average value of 62 mm and a standard deviation of 28 mm. Three rainfall events of 34 mm, 95 mm and 76 mm occurred during 2013, three events of 27 mm, 35 mm and 74 mm during 2014, and one of 89 mm during 2015. In 2016, none of the rainfall events could generate runoff in experimental plots. Results indicated that runoff amounts did not vary largely among all sole and intercropped treatments and ranged from 3–30 mm. The mean daily runoff was the lowest (11–12 mm) from treatments T4 (CB), T5 (S+GG) and T7 (S+CB) and the highest (14–15 mm) from T1 and T2 (S and PM) treatments. Annually, the mean runoff was the lowest (26–27% of rainfall) from T7 and T8 treatments, and the highest percentage of rainfall as runoff (33–35% of rainfall) was from the sole cereal treatments (T1 and T2) (Table 1). This suggested that cropland with a close-growing legume intercropping system reduced the amount of generated runoff water in comparison to sole cereal-cropping plots. Tukey's Honestly Significant Difference (HSD) test revealed that the mean runoff values for sole cereals, legumes and their intercropping were not significantly different from each other at a 5% level of significance. The runoff-producing rainfall received during 2013, 2014 and 2015 was 205 mm, 137 mm and 89 mm, respectively; however, minimum runoff was generated during 2014 when the rainfall was not the lowest in 3 years. This finding indicated that runoff amount not only depends upon the total rainfall amount but also on the rainfall intensity and its temporal distribution.

Effect of cereal-legume intercropping on runoff

Findings confirmed that cereal-legume intercrops generated less runoff as compared to sole cereals, which might be due to high infiltration rates and saturated hydraulic conductivity from added taproot penetration, and large evapotranspiration rates from added leguminous plants. Legumes such as green gram have taproots that reach deep into the soil surface with a 1.27 cm diameter that allows water to percolate down along with root pathways. Legumes rich in nitrogen increased and supported earthworms as well as their burrows, which enhanced soil porosity and promoted water percolation. Also, in plots of cereal-legume intercropping, runoff generation was diminished due to increased canopy cover that reduced raindrop impact, flow velocities, amount of runoff, and increased infiltration into the soil. The findings concluded that runoff generation depends not only on the rainfall magnitudes but also on the rainfall intensity and distribution over time.



Mean runoff and mean soil loss values obtained for sole cereals, legumes and cereal-legume intercropping (S-sorghum, PM-pearl millet, GG-green gram, and CB-cluster bean)

Laboratory testing for determining soil and nutrient losses

Runoff water collected inside the tank was stirred well and three runoff water samples of 500 ml quantity were collected to determine the amount of soil loss. All three samples were then mixed to obtain composite runoff water samples, which were then transferred to the laboratory of the Regional Research Station, ICAR-CAZRI, Bhuj, Gujarat. In the laboratory, eroded wet soil was separated from runoff water using Whatman No.1 filter paper possibly on the same day. The obtained wet soil samples were oven-dried at 50°C for 48h and weighed to determine the amount of soil loss for 8 treatments. In addition, samples of topsoil were collected from 8 treatment plots in post-monsoon seasons. The collected samples were analysed to determine soil chemical properties, i.e. soil organic carbon, available phosphorus (P_2O_5) and potassium (K_2O) by using Degtjareff method, ascorbic acid method, and neutral ammonium acetate method, respectively.

Results indicated that the amount

Table 1. Treatment-wise mean and critical difference values of runoff, soil loss, and soil quality during 2013–15

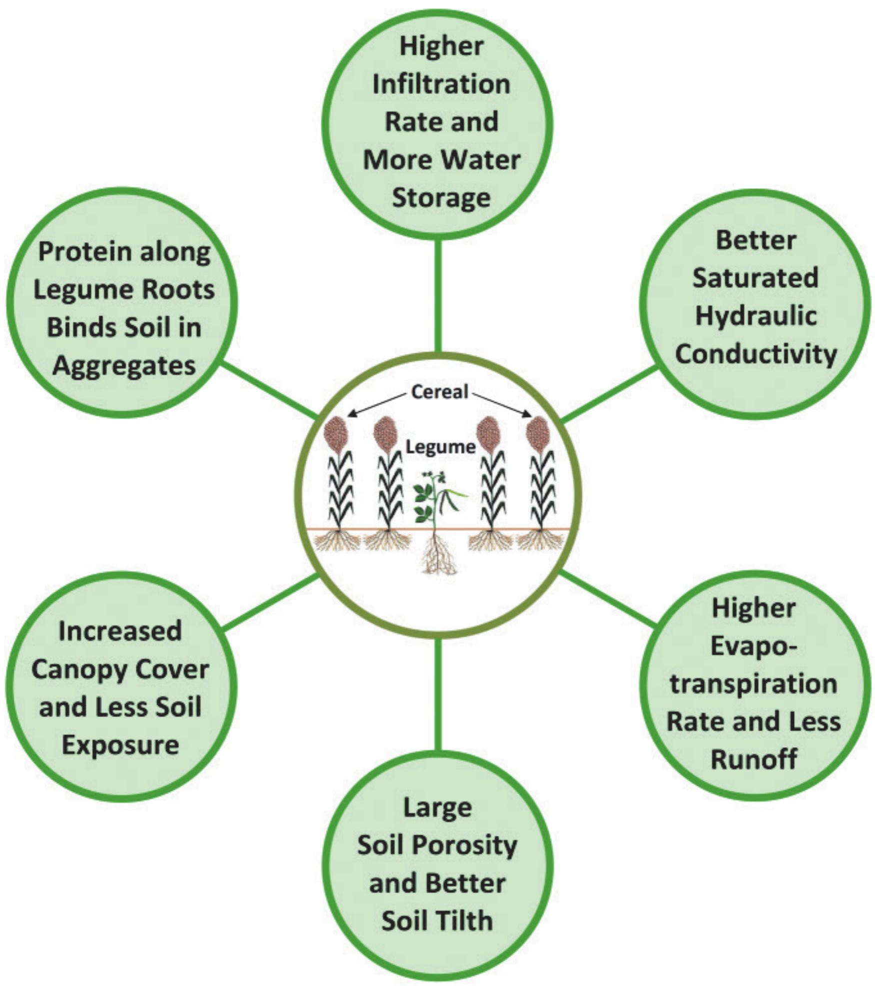
Treatment	Runoff (mm/year)	Soil Loss (kg/ha/year)	Soil Phosphorus (kg/ha/year)	Soil Potassium (kg/ha/year)	Soil Organic Carbon (t/ha/year)
T1	34.95a	50.73a	17.26a	166.39a	17.95a
T2	33.30a	52.73a	19.54ac	179.44ad	23.23ad
T3	32.31a	25.27b	29.34b	266.86b	41.95b
T4	28.83a	29.71b	22.12c	228.15c	33.36bd
T5	28.85a	22.81b	34.17d	270.78b	64.85c
T6	32.69a	33.82b	21.84c	199.61d	29.11d
T7	26.21a	30.15b	25.79bc	253.04bc	36.00b
T8	27.06a	39.93b	20.70ac	197.62d	24.33ad

of soil loss ranged from the lowest (0.50–30.54 kg/ha) for T4 (CB) followed by (0.54–33.94 kg/ha) T3 (GG) and the highest (3.23–43.82 kg/ha) for T1 (S). The daily lowest mean soil loss (9.78±7.19 kg/ha) occurred from T5 (S+GG) followed by 10.83±11.01 kg/ha from T3 (GG). Whereas, the daily highest mean soil loss was from cereals of pearl millet (T2: 22.60±11.02 kg/ha) and sorghum (T1: 21.74±13.24 kg/ha). On an annual time scale, the lowest mean soil loss occurred from S+GG intercropping (T5: 22.81±12.42 kg/ha) followed by sole green gram (T3: 25.27±20.44 kg/ha) and sole cluster bean (T4: 29.71±21.17 kg/ha). On the other hand, the highest soil loss was recorded from two cereals of pearl millet (T2: 52.73±21.22 kg/ha) and sorghum (T1: 50.73±29.27 kg/ha). The mean soil loss from plots of cereal-legume intercropping (T4-T8) was significantly different from that of plots of cereal crops (T1 and T2) as the value of Tukey's HSD ($P<0.05$) was less than the difference among their mean soil loss values. This finding indicated that legumes and legume-cereal intercropping with conservation of nutrients effectively resisted erosion of the soil from agricultural fields. Furthermore, it was estimated that soil losses from legume-intercropping treatments of sorghum, i.e. S+GG and S+CB were 55% and 33% lower than that occurring from sole sorghum. Similarly, soil losses from legume-intercropping treatments of pearl millet, i.e. PM+GG and PM+CB were 43% and 24% lower than that occurring from sole pearl millet.

The lowest mean annual value of soil phosphorous was for sole cereals of sorghum (T1: 17.26±1.17 kg/ha) and pearl millet (T2: 19.54±1.72 kg/ha) and the highest for S+GG intercropping (T5: 34.17±4.32 kg/ha) followed by sole GG (T3: 29.34 ±4.61 kg/ha). Likewise, the lowest mean amount of soil potassium was for two sole cereals of sorghum (T1: 166.39±12.2 kg/ha) and pearl millet (T2: 179.44±8.05 kg/ha) and the highest for S+GG intercropping (T5: 270.78±0.42 kg/ha) followed by sole green gram (T3: 266.86±27.09 kg/ha). Similarly, the lowest mean value of organic carbon was for cereals of sorghum (T1: 17.95±2.75 t/year/ha) and pearl millet (T2: 23.23±5.05 t/year/ha) and the highest for S+GG intercropping (T5: 64.85±11.64 t/year/ha) and sole green gram (T3: 41.95±6.96 t/year/ha). The highest amounts of nutrients in the case of legume (GG) and cereal-legume intercropping (S+GG) emphasized the role of legumes in nutrient conservation on croplands. The amount of soil nutrients increased over three years, which was due to added fertilizers in all the treatment plots.

Effect of cereal-legume intercropping on soil loss and nutrients

Findings indicated the lowest soil losses from plots of legumes and cereal-legume intercropping. In legume intercropping, spaces between consecutive crop rows became narrow due to enhanced crop cover over the land, which resulted in less exposure of soil surface to rainfall impact for detachment. Thus, legumes and cereal-legume intercropping conserved nutrients and resisted soil erosion effectively from agricultural fields. Protein, glomalin, symbiotically along the roots of legumes served as the glue that bound soil together into stable aggregates. Therefore, pore space, as well as soil tilth, was increased and soil erodibility and crusting got reduced. Relatively low soil losses may also be due to the shallow and fibrous rooting system of cereal crops of sorghum and pearl millet that worked better with tap root system of leguminous crops in holding and binding the soil particles together and resisting their detachment and erosion. Legumes may expand or keep an adequate carbon-nitrogen ratio and increase preserving soil organic carbon stock. When raindrops struck the soil surface, the kinetic energy of



Advantages of cereal-legume intercropping over sole cereal crops raindrops was used to overcome the bonds that held the soil particles and bonds were broken or weakened. As a result, loosely-attached and detached soil particles were easily transported when the soil was ploughed or cultivated. Recently, high-intensity rainfall was observed in the arid region of the study area, and annual rainfall was found to be significantly rising in the Kachchh district. Under the changing rainfall patterns in the study area, the results of this study are practically important for developing suitable adaptation plans such as the adoption of intercropping of legumes with cereals in order to reduce the impact of raindrops on soil surface and minimize the soil loss from agricultural land.

Runoff, soil loss and soil nutrients are invariably and closely linked to each other, and hence, any interventions that effectively restrict runoff should also reduce the amount of soil loss and enhance soil nutrients. Therefore, the lowest soil nutrients in plots of two cereal crops, i.e. sorghum and pearl millet were likely due to relatively more exposure of soil surface to raindrop impact, and subsequent soil erosion and nutrient loss. In contrast, the highest nutrients in cereal-legume intercropping plots were due to enhanced canopy cover resulting in reduced runoff, soil erosion and nutrient loss. Thus, transportation of soil through erosion lowered the availability of soil nutrients, especially organic carbon, nitrogen, phosphorus and potassium.

SUMMARY

Soil erosion from cultivated lands is the prominent cause of land degradation in the arid region of Gujarat. In recent years, rainfall patterns in arid regions are considerably changing with the occurrence of more intense short-duration rainy storms due to climate change and variability. Cereal-legume intercropping has the potential to combat the worsening impacts of climate variability in arid region agriculture. Leguminous crops such as green gram and cluster bean when intercropped with dominant cereal crops of the arid region, i.e. sorghum and pearl millet, proved beneficial in reducing soil and nutrient losses substantially from agricultural fields and in conserving rainwater within the soil root zone for productive use.

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