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# Effect of gypsum integrated with organic amendments on hydrologic attributes, crop productivity and soil health of table land in Chambal river basin

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## ABSTRACT

A field experiment was conducted to evaluate the effect of soil amendments on runoff, soil loss, nutrient loss, crop productivity and soil properties in table lands of Chambal ravines, western India. Eight treatments consisting of gypsum, crop residue (CR) and farm yard manure (FYM) applied solely and in combination with each other with recommended fertilizer dose (RDF) and one control were imposed on soybean-mustard cropping system. Observations recorded over three years revealed that lowest runoff (15.5-17.9%) and soil loss (2-2.2 t $ha^{-1}$) was found in RDF + Gypsum + CR, RDF + Gypsum + CR + FYM and RDF + Gypsum + FYM, whereas, highest runoff (25.5%) and soil loss (4.2 t $ha^{-1}$) was observed in control. The magnitude of runoff and soil loss reduction over control varied between 35 and 51% in combined and 23 and 41% sole amendment treatments respectively. The lowest nutrient loss was recorded in combined (1.79:0.21:15.1 and11.9 kg $ha^{-1}$) followed by sole (2.17:0.23:17 and 14.5 kg $ha^{-1}$) amendment applied treatments. Combined application of CR, gypsum and FYM enhanced soil moisture (0-30 cm) content by 37% over control plots. Application of gypsum and organic amendments decreased exchangeable sodium percentage (ESP), improved soil organic carbon (SOC) and available nutrient content. Significant improvement in soybean (1.25-1.31 t $ha^{-1}$) and mustard (1.36-1.40 t $ha^{-1}$) grain yield was observed in gypsum with organic amendment treatments compared to only RDF. System productivity in terms of mustard grain equivalent yield indicated that the application of soil amendments is the best option for reducing runoff, soil-nutrient loss, reclaiming soil properties and improving oilseed production.

## 1. INTRODUCTION

Soil erosion is a serious threat to the ecosystem, removes essential plant nutrients, causes soil layer loss, reduces rooting depth, causes soil structure deterioration, reducing infiltration, resulting in negative nutrient balances and lowering crop yields (Lal *et al.,* 2015; Li *et al.,* 2020). India has 120 Mha of degraded land out of which more than 80% degradation is due to water erosion (ICAR-NAAS, 2010). Recent report by Sharda and Ojasvi, (2016) highlighted that soil erosion in India varies from <5 Mg $ha^{-1}$ $yr^{-1}$ to >40 Mg $ha^{-1}$ $yr^{-1}$. It is estimated that India suffers 13.34 M t as annual loss in crop production worth 205.32 billion due to water erosion (Sharda and Dogra, 2013). Quantitative understanding of runoff and soil loss in relation to farmland is, therefore, important from theoretical and practical point of view (Huo *et al.,* 2020; Singh *et al.,* 2020). In India, black soils are major soils covering 73 M ha and are highly vulnerable to water erosion (Rajput *et al.,* 2009). Black soils associated with Chambal ravines of Rajasthan state of western India suffer from soil salinity, declining organic carbon, lower nutrient availability, poor aggregation and water transmissivity which threatens sustainability of crop production (Rashmi *et al.,* 2021).

Resource conservation through application of organic and inorganic amendments for reducing soil erosion could minimise the adverse effect of land degradation. Gypsum known as multitude amendment plays many role by preventing soil loss by enhancing infiltration, providing sulfur nutrition to oilseed crops and reclaiming salt affected soils (Zoca and Penn, 2017; Rashmi *et al.,* 2022). Gypsum accelerates Na- Ca exchange process, flocculates soil colloids, imparting stability to soil structure, increases infiltration and reduce surface sealing/crusting (Murtaza *et al.,* 2017; Watts and Dick 2014). Truman *et al.* (2010) reported that gypsum increased infiltration, reduced runoff and sediment loss by 26, 40 and 58%, respectively in rainfall simulation study. Organic manure and CR application protects soil surface aggregates from raindrop impact (Ngangom *et al.,* 2020) and provides physical protection sediment and water loss (Turmel *et al.,* 2015).

Though gypsum and organic amendments have been extensively studied for correcting sulfur deficiency and reclamation of sodic soils, there is very limited study of these amendments on runoff and soil loss under soybean-mustard system. It has been hypothesized that application of soil amendments with RFD in soybean crop will reduce runoff, soil loss, nutrient loss and improve crop yield on table landscape of Chambal river basin of western India. To test this hypothesis, a field experiment was conducted with the following objectives: (i) to evaluate the efficacy of different soil amendments (gypsum, FYM, CR) on runoff, sediment loss and nutrient loss; (ii) to evaluate the effect of soil amendments on soybean yield and soil properties in table lands of Chambal ravines.

## 2. MATERIALS AND METHODS

### Study Site

The experimental field was located at ICAR-Indian Institute of Soil and Water Conservation, Research Farm, Kota (25º13'N latitudes and 75º52'E longitudes; 267 m above mean sea level) which is a table land adjacent to ravine (severe form of gully eroded areas) in semi-arid region of south eastern Rajasthan, India. The climate is characterized by a mono modal rainfall regime, with a three to four-month humid season (July-Oct) and eight to nine-month dry season (Nov-June) as shown in Fig. 1. The research farm comprises of two distinct landscapes agricultural table lands (34 ha) and ravinous lands (34 ha). The soil is classified as *Typic Chromousterts* belong to Kota series with silty clay loam texture. The soil had pH 8.1-8.3, bulk density (BD) of 1.65 Mg $m^{-3}$, SOC of 3-3.5 g $kg^{-1}$, available nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) were 126-254 kg $ha^{-1}$, 6.6-7.8 kg $ha^{-1}$, 356-545 kg $ha^{-1}$ and 3.2-4.4 mg $kg^{-1}$, respectively.

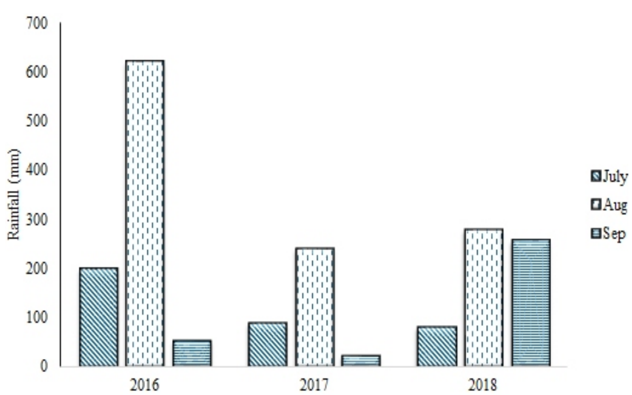



**Fig. 1. Rainfall distribution during cropping season (2016-2018)**

### Treatment Details

The experiment was conducted on runoff plots with dimension of 10 × 5 m in soybean-mustard cropping system. The experimental fields had gentle slope gradient of 1 to 2%. Soybean crop (JS 9560) and mustard crop (Pusa bold) was sown during *kharif* (July) and *rabi* (Nov) season of 2016-2018 for three-year rotation. The field experiment was laid out in randomized block design with three replications with combinations of RDF with either sole or combined application of gypsum, CR and FYM amendments under soybean-mustard system. The 100% RDF used for in terms of N: $P_2O_5$: $K_2O$ for soybean and mustard was 20: 40: 40 and 80: 40:0 kg $ha^{-1}$, respectively. Gypsum was applied (2.5 t $ha^{-1}$) to the soil surface by uniformly mixing into 0.10-0.15 m soil layer by using harrow in *kharif* season (before onset of monsoon) prior to soybean sowing. The well decomposed FYM (10 t $ha^{-1}$) was applied to soybean crop 30 days before sowing. In soybean crop, CR of mustard stover (@ 3 t $ha^{-1}$) and in mustard crop, soybean stover (@1.5 t $ha^{-1}$) was applied as mulch during cropping season. The various combination of eight treatments imposed on soybean-mustard system were T1: Control (absolute control); T2: RDF for soybean / mustard; T3: RDF + Gypsum; T4: RDF + farm yard manure FYM; T5: RDF + CR; T6: RDF + Gypsum + CR; T7: RDF + Gypsum + FYM; T8: RDF + Gypsum + CR + FYM. Soybean and mustard crops were harvested manually in first fortnight of Oct and March, respectively in three years.

### Rainfall, Runoff, Soil Loss and Nutrient Loss Data Analysis

Rainfall distribution during the study period was recorded with rain gauge installed at automatic weather station on the research farm. Total rainfall received during 2016, 2017 and 2018 was 1010.4, 495, and 798 mm, respectively (Fig.1). The runoff and soil loss were estimated for three consecutive years (2016-2018). The runoff and soil and nutrient losses from the experimental plots were measured through runoff and soil loss measuring devices which consisted of 1.5 H-flume, Coshocton wheel and water level recorder over the stilling tank. Runoff was measured during the whole *kharif* season (July- Sept) for three consecutive years. From the total runoff collected in the sedimentation tank through Coshocton wheel after each rainfall-runoff all event, 1 litre runoff samples were collected in a glass bottle after homogenizing the runoff in the tank. These samples with runoff water and suspended soil particles were taken into laboratory for further analysis of sediment and nutrients. The soil samples were allowed to settle down to obtain clear supernatant which was decanted later on. Remaining soil samples were dried at 105°C in oven to determine the soil loss. Sediment was collected from each tank for nutrient loss estimation. Sediment nutrient analysis of total N, P and K was performed by standard methods. Total N was determined by Kjeldhal digestion and distillation procedure. Total P and K by di-acid digestion and determined in spectrophotometer and flame photometer. The soil samples were collected after harvest of three years of cropping for determining changes in soil properties under amendment application. The mean weight aggregate (MWD) of water stability aggregates was measured by Yoder apparatus (Kemper and Rosenau, 1986). The soil chemical properties such as ESP by USDA method (Richard, 1954), soil pH, SOC and available N, P, K and S were analyzed by standard procedures (Jackson, 1973). Soil moisture was determined by gravimetric method at harvesting stage of mustard crop.

## Statistical Analysis

The collected data from various parameters were statistically analyzed using analysis of variance (ANOVA) technique as applicable to randomized complete block design. The superior treatments were determined by comparing treatment pairs using least significant differences (LSD) estimated at 5% probability level ($p \leq 0.05$).

## 3. RESULTS AND DISCUSSION

## Rainfall Distribution

During the experimental period of three years (2016-2018), except for 2017, other two years recorded almost similar amount of rainfall in 2016 (838 mm) and 2018 (798 mm) during the cropping period of soybean. Effective rainfall was 655, 220, and 608 mm for 2016, 2017, and 2018, respectively. This effective rainfall produced 17, 4 and 24 runoff events for 2016, 2017, and 2018, respectively during *kharif* season (July-Oct). Among three years, 2016 and 2018 received higher rainfall as compared to 2017. In the year 2016, rainfall in the month of July, Aug and Sept was 199 (19.7%), 620 (61.4%) and 52 (5.2%) mm, respectively. However, during 2017, there was only four effective rainy days. Of which, two were moderate and two were heavy rainfall events. During 2017, total rainfall received was 495 mm, of which July, Aug and Sept received 86.4 (18%), 240 (52.4%) and 20 (4.3%) mm, respectively. In 2018, the rainfall received during July, Aug and Sept was 79.8 (10%), 279 (35%) and 255 (32%) mm, respectively. The rainfall period (2016-2018) during the crop period was given in Fig. 1.

## Effect of Soil Amendments on Hydrological Attributes

### *Runoff and soil loss*

The hydrological attributes such as runoff and soil loss data for three years were recorded during *kharif* season in soybean crop are shown in Fig. 2. The average runoff and soil loss during three years varied between 25 and 15.6% of total rainfall and 4.2 and 2.0 t ha$^{-1}$, respectively. During 2017-18, rainfall was less (498 mm) resulting in the lowest soil loss and runoff percentage as compared to other two years. Comparing the effect of amendments on runoff and soil loss, it seems that relative to control and T2 (RDF), gypsum applied solely (T4) and combined with CRs (T6) and FYM (T8) was effective in reducing runoff and soil loss. In sole amendment treatments, the lowest runoff and soil loss was observed in RDF + Gypsum (18.2% and 2.2 t ha$^{-1}$) and highest in RDF + FYM (20.2% and 2.8 t ha$^{-1}$), respectively. However, combined amendment treatments recorded lowest runoff and soil loss in RDF + Gypsum + CR (15.5% and 2.0 t ha$^{-1}$), RDF + Gypsum + FYM (18% and 2.2 t ha$^{-1}$) and RDF + Gypsum + CR + FYM (15.8% and 2.1 t ha$^{-1}$). The lower runoff and soil loss in combined and sole amendment treatments was due to gypsum application and CR mulch which covered soil surface, binding the soil particles especially during initial 30-45 days after sowing (DAS), when soybean crop canopy was less. Gypsum dissolves with rain water and increase the electrolyte concentration thereby reducing clay dispersion and decrease soil sealing, thus reduce runoff (Zoca and Penn, 2017; Rashmi *et al.,* 2018). Further gypsum addition with CR and FYM reduced ESP, improved soil water infiltration thereby reducing

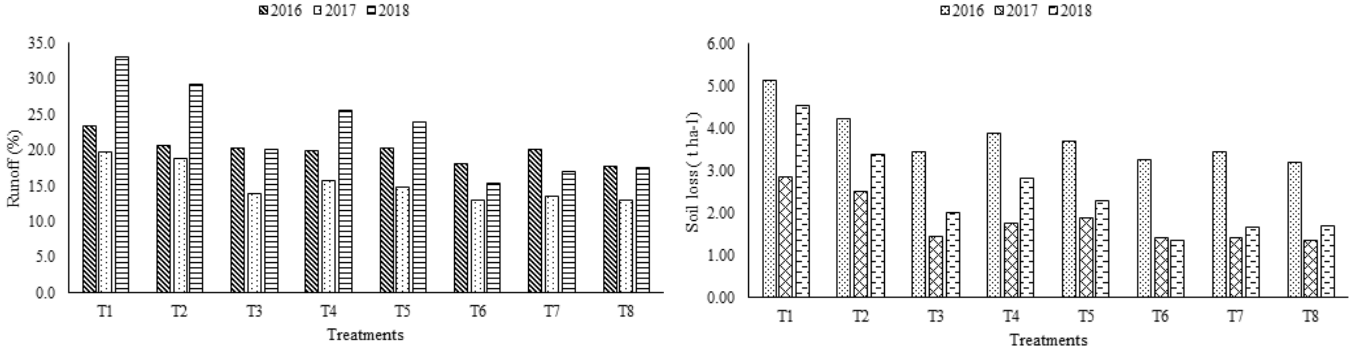



**Fig. 2. Runoff and Soil loss under different soil amendment treatments**

runoff and sediment delivery compared to control plots (Rashmi *et al.,* 2021; Bello *et al.,* 2021). Our results were comparable with those of Yu *et al.* (2003) who reported application of gypsum at the rate of 2 and 4 Mg ha$^{-1}$ reduced clay dispersion and surface sealing with improved soil aggregation. However, soil loss and runoff were highest in control plots without amendment application. Poor crop growth and canopy cover deteriorate soil health and increase velocity of runoff. Plot experiment elsewhere reported by Truman *et al.* (2010) and Baptista *et al.* (2015) highlighted that control plots without amendments recorded higher soil loss, runoff and nutrient loss compared to amendment applied treatments. In sole amendment treatments, pooled data of three years showed that average percent reduction in runoff varied between 19.3 to 27.4% and soil loss varied from 33 to 49% compared to that of only fertilizer (RDF) applied plots (Fig. 3). Similarly, average reduction in percent runoff and soil loss in combined amendment treatments varied from 31.4 to 36.9% and 48 to 52%, respectively. Soil amendments application imparts surface cover and roughness that reduce raindrop impact thereby, decreasing runoff and soil loss. Significant percent reduction in runoff (28.7%) and soil loss (45%) across amendment treatments as compared to control was due to improvement in soil properties with application of gypsum and organic amendments. Similar results were reported by Favaretto *et al.* (2006) and Truman *et al.* (2010) who also reported addition of gypsum amendment significantly reduced soil loss (upto 58%) and nutrient loss (59-80%) as compared with control plots. Compared to control, application of amendments improved soybean growth and canopy cover, providing better surface cover to reduce runoff and soil loss. Singh *et al.* (2014) also reported lower erosion losses under soybean-based intercrops in vertisol of central India.

### *Nutrient loss*

SOC and nutrient loss almost followed similar trend as of runoff and soil loss (Fig. 4). Among nutrients N, P, K: lowest and highest loss was observed in P and K, respectively. The losses with respect to SOC, total nitrogen, phosphorus and potassium varied between 12 to 25, 1.71 to 2.76, 0.20 to 0.27 and 14.8 to 21.4 kg ha$^{-1}$, respectively. Among the sole amendment applied plots, lowest total NPK and SOC losses was recorded in RDF + gypsum plots (N:P:K:SOC; 2.1 :0.22: 15.3: 13.4 kg ha$^{-1}$), compared to RDF + CR (N:P:K:SOC; 2.2 :0.22: 17.7: 13.9 kg ha$^{-1}$) and RDF + FYM (N:P:K:SOC; 2.26 :0.25: 17.9:16.1 kg ha$^{-1}$) plots. Corresponding nutrient and SOC loss in RDF + Gypsum + CR (1.81:0.21:15.3:12.2 kg ha$^{-1}$), RDF + Gypsum + FYM (1.85:0.21:15.3:12 kg ha$^{-1}$) and RDF + Gypsum + FYM + CR (1.71:0.21:14.8:11.7 kg ha$^{-1}$) were recorded in combined amendment treatments. Compared to a study conducted on vertisol of central India (Singh *et al.* 2020), sediment N, P and K losses in the present study were lower under amendment treatments. In general, maximum reduction in nutrient and SOC loss was observed in combined followed by sole amendment treatments.

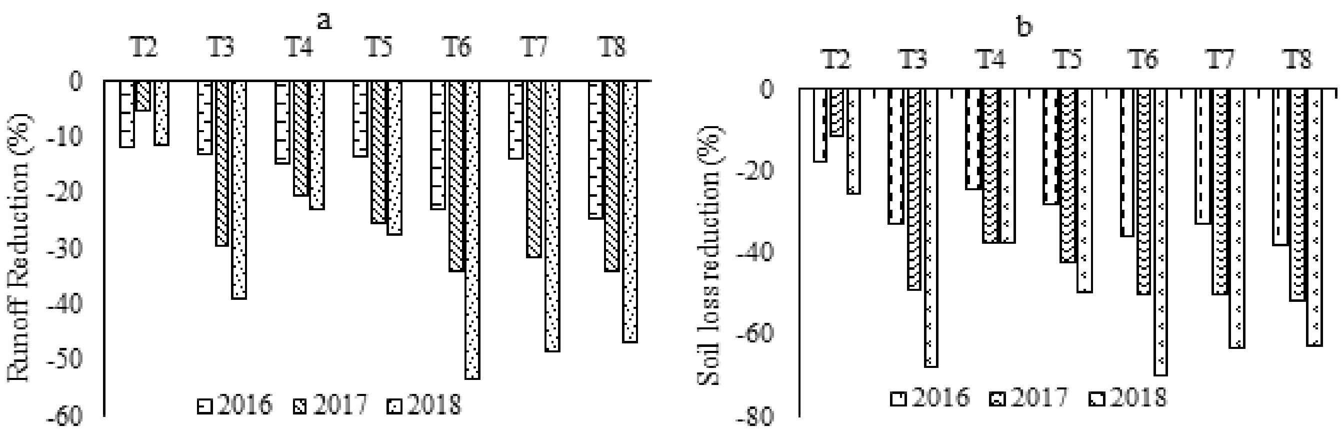



**Fig. 3. Reduction in runoff and soil loss as influenced by soil amendments**

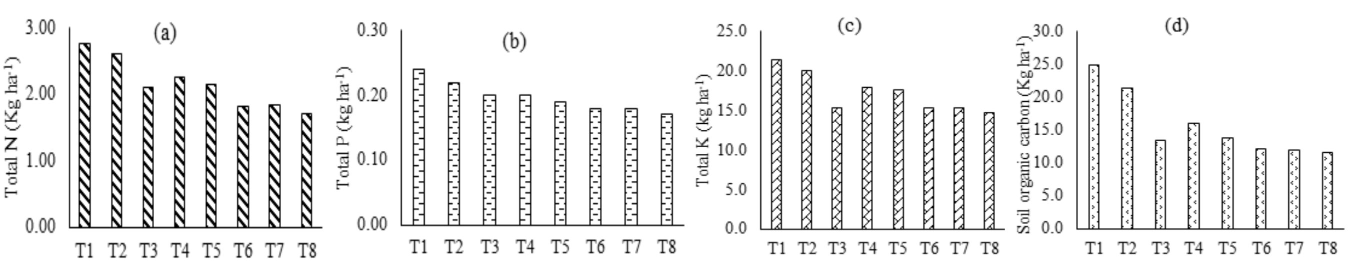



**Fig. 4. Average nitrogen (a), phosphorus (b), potassium (c) and soil organic carbon (d) loss under different amendment treatments**

Application of gypsum is effective in improving infiltration and decreasing runoff in soil prone to crust formation and therefore could alter nutrient movement (Watts and Dick, 2014; Zoca and Penn, 2017). Across treatments highest total NPK and SOC loss was registered in control (2.76 : 0.27 : 20 : 25 kg $ha^{-1}$) and RDF (2.62: 0.27:20: 21.5 kg $ha^{-1}$) treatments without soil amendments. Baptista *et al.* (2015) reported cropping system without any external amendment produced higher nutrient loss whilst the lowest was observed in plots with combined amendment application with chemical fertilizers.

### *Soil moisture retention*

The average soil moisture retained after three years of soybean - mustard cropping system is presented in Fig. 5. The soil moisture content across treatments increased in sub-surface depth. In 0-15 cm soil depth, soil moisture content at harvest was significantly higher in RDF + Gypsum + CR + FYM which was statistically on par with RDF + Gypsum + CR, RDF + Gypsum + FYM in the cropping system. Similarly, at lower depth of 15-30 cm depth, higher moisture conservation was recorded in RNPK + Gypsum + CR, followed by RNPK + CR, RDF + Gypsum + FYM and RDF + Gypsum + CR + FYM treatments. Soil moisture content depletion was highest in control at all depth across the years. Without amendment application and poor surface cover, evaporation losses increased, which might have attributed to low moisture content in control plots. In 30-45 cm depth, soil moisture content did not vary significantly in plots under amendment treatments, however, it was significantly higher than control plot. Relatively higher soil moisture conservation was observed in CR applied treatments which reduces surface runoff and evaporation losses. With reduced moisture loss under mulch treatments enhances moisture conservation in soil profile (Ngangom *et al.,* 2020). Improvement in soil properties with amendment application and better crop growth might have contributed in enhancing soil moisture conservation. Relatively higher soil moisture content under amendments attributed to higher water infiltration thereby reducing soil erosion (Turmel *et al.,* 2015).

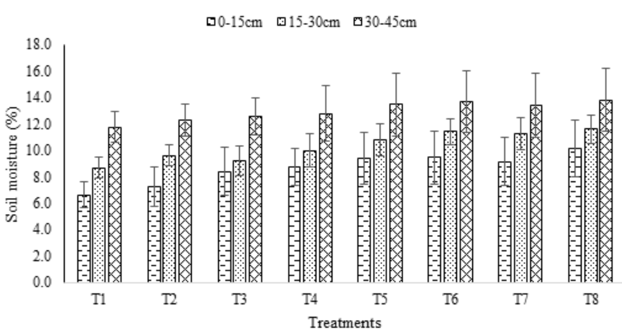


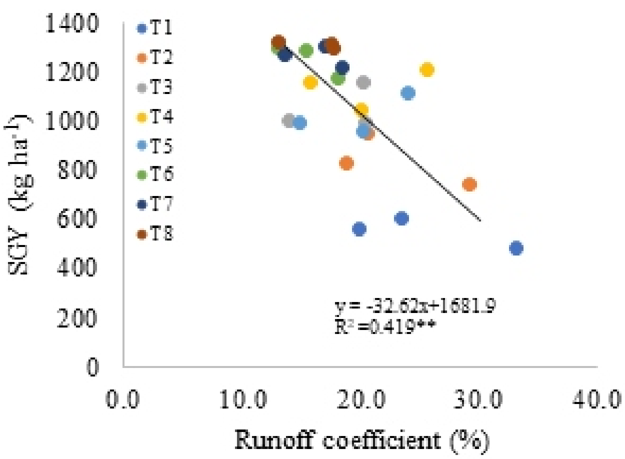

**Fig. 5. Average soil moisture content (%) after harvest of mustard crop**

### Effect of Soil Amendments on Crop Productivity

Soybean and mustard yield varied significantly ($p < 0.05$) across the treatments. Crop yield data for the three years (pooled data) are as shown in Table 1. In soybean crop, (RDF + Gypsum + FYM + CR) and (RDF + Gypsum + CR) produced highest yield. The lowest grain and stover yield was recorded in control and RDF treatments. A significant negative relationship between soybean grain yield with runoff and soil loss was observed (Fig. 6). Soybean grain yield decreased with increase in runoff and soil loss. The higher runoff and soil loss cause greater loss of essential nutrients from topsoil, consequently reducing crop yield. However, conjunctive application of gypsum and CR significantly reduced soil loss and runoff, enhanced nutrient availability and soil moisture for longer period which contributed for higher yield (Zoca and Penn 2017; Bello *et al.,* 2021). Soybean grain yield improved by 46-50% and 22-32% over RDF treatment in combined and sole amendments treatments, respectively. The residual fertility of gypsum and FYM on mustard crop yield was clearly visible with highest grain yield in the combined amendment treatments. The pooled mean of grain yield recorded an increase of 55-60% in RDF + Gypsum + CR, RDF + Gypsum + CR + FYM and RDF + Gypsum + FYM over the RDF treatments. In sole amendment treatments, mustard grain yield improved by 23-32% over the RDF. Application of gypsum improved S availability for oilseed crops and other amendments like

**Table: 1**
**Impact of soil amendments on soybean-mustard yield and system productivity**

| Treatments | Soybean yield (t $ha^{-1}$) | Mustard yield (t $ha^{-1}$) | System productivity (t $ha^{-1}$) |
|---|---|---|---|
| Control | 0.55 | 0.55 | 0.97 |
| RDF | 0.84 | 0.85 | 1.54 |
| RDF + Gypsum | 1.05 | 1.10 | 1.85 |
| RDF + FYM | 1.14 | 1.11 | 1.97 |
| RDF + CR | 1.02 | 1.04 | 1.81 |
| RDF + Gypsum + CR | 1.25 | 1.39 | 2.33 |
| RDF + Gypsum + FYM | 1.26 | 1.36 | 2.29 |
| RDF + Gypsum + CR + FYM | 1.31 | 1.38 | 2.35 |
| CD ($p$ = 0.05) | 0.132 | 0.102 | 0.139 |



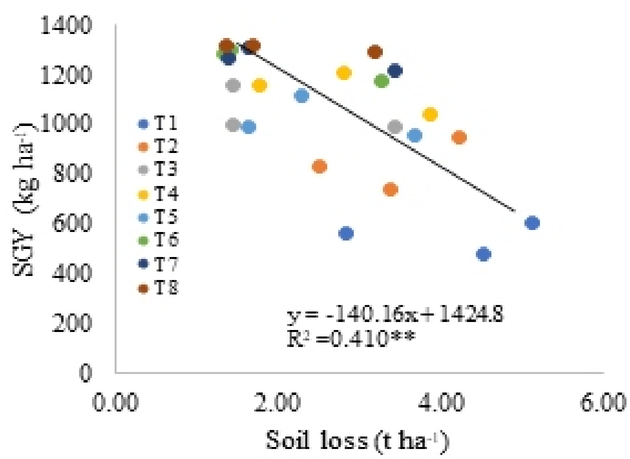




**Fig. 6. Regression relationship of soybean grain yield (SGY) with runoff and soil loss (**denotes significance at $p < 0.05$)**

**Table: 2**
**Post harvest soil properties in different soil amendment treatments**

| Treatments | pH | ESP (%) | SOC (g kg$^{-1}$) | Available nutrients (kg ha$^{-1}$) | | | | MWD (mm) | DHA (ug g$^{-1}$ soil day$^{-1}$) | MBC (mg C kg$^{-1}$soil) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | P | K | S | | | |
| Control | 8.24 | 16.9 | 5.10 | 112.6 | 5.9 | 396.0 | 6.9 | 0.45 | 10.4 | 91.7 |
| RDF | 7.97 | 16.4 | 5.90 | 187.8 | 10.8 | 462.8 | 13.5 | 0.50 | 12.4 | 129.3 |
| RDF + Gypsum | 7.70 | 13.3 | 6.60 | 236.5 | 11.8 | 469.5 | 53.6 | 0.58 | 14.2 | 152.3 |
| RDF + FYM | 7.76 | 14.3 | 7.10 | 251.6 | 15.0 | 471.0 | 24.6 | 0.56 | 15.2 | 202.7 |
| RDF + CR | 7.81 | 14.5 | 6.90 | 229.6 | 13.8 | 481.3 | 19.7 | 0.55 | 14.5 | 195.6 |
| RDF + Gypsum + CR | 7.65 | 12.2 | 6.8 | 258.6 | 15.6 | 474.8 | 61.9 | 0.59 | 15.9 | 208.0 |
| RDF + Gypsum + FYM | 7.68 | 12.7 | 7.20 | 266.9 | 15.5 | 496.8 | 65.4 | 0.60 | 16.7 | 219.7 |
| RDF + Gypsum + CR + FYM | 7.61 | 12.6 | 7.50 | 271.3 | 15.7 | 493.8 | 66.7 | 0.63 | 18.1 | 228.7 |
| CD ($p$ = 0.05) | 0.11 | 1.14 | 0.04 | 33.5 | 2.20 | 24.1 | 12.5 | 0.034 | 2.7 | 24.7 |

FYM improved $KMnO_4$-N, Olsen-P and exchangeable K content in soil. Both gypsum and CR application reduced soil loss and runoff, also enhanced nutrient availability and soil moisture for longer period. Total system productivity of soybean-mustard was highest under combine use of RNPK + Gypsum + CR + FYM, which was significantly higher than NPK alone (Table 2). Higher grain yield with gypsum application due to beneficial gypsum effect on soil properties, improved root length enhancing nutrient uptake, water movement (Zoca and Penn, 2017; Rashmi *et al.,* 2023), better $Ca^{2+}$: $Na^{+}$ ratios in soil solution (Murtaza *et al.,* 2017). Organic amendments on the other hand, has higher quantity of nutrients and supports micro flora, which undergoes mineralization increases bioavailability of nutrients for crop uptake (Singh *et al.,* 2020). Combined application of gypsum with organic amendments reduced soil erosion, leading to better nutrient conservation thus, providing better environment for crop growth and productivity.

## Effect of Soil Amendments on Soil Properties

The soil properties under different sole and combined amendment treatments after the three years of soybean-mustard cropping are presented in Table 2. Slight but significant ($p$<0.05) changes in soil pH was recorded in gypsum applied plots after third year of the experiment and was significant compared to RDF and control (Table 1). ESP values were maximum in control and minimum in plots with sole and combined application of gypsum. Conjoint use of amendment application registered highest reduction in soil pH and ESP, RDF + Gypsum + CR + FYM (pH by 0.58 unit and ESP by 26%)~RDF + Gypsum + CR (pH by 0.54 unit and ESP by 28%), RDF + Gypsum + FYM (pH by 0.51 unit and ESP by 24%) and RDF + Gypsum (pH by 0.49 unit and ESP by 22%) over control. The values of ESP decreased significantly in amended soils, the greatest decrease was observed in gypsum with organic amended soils, while the soils without amendments and fertilizers (control plot) showed highest ESP values throughout experimental period (Rashmi *et al.*, 2021). Organic amendment (FYM, CR) significantly ($p$<0.05) increased SOC over the un-amended treatments. SOC values in the RDF + Gypsum + CR and RDF + Gypsum + FYM and RDF + Gypsum + CR + FYM plots increased by 34.8-47%, respectively over control treatment. Similarly, in RDF + FYM, RDF + CR and RDF +

Gypsum treatments SOC improved by 31-39.4% than control. This indicate that organic amendment can improve soil fertility levels by increased soil carbon levels beside ameliorating the harmful effects of sodicity (Bandyopadhayay *et al.,* 2021). Thus, there is potential to sequester carbon with addition of organic amendments in soybean-mustard cropping system on long term basis. Available N, P and K content in soil significantly improved in all RDF and amendment applied treatments as compared to control. Similarly, gypsum applied treatments recorded three times higher S availability compared to RDF treatment. Thus, gypsum played an additional role in reducing S deficiency and improving oilseed crop yield (Chahal *et al.,* 2020). The amendment application had significant effect ($p$<0.05) on MWD in all the treatments. Average MWD was significantly higher than the control in the RNPK + Gypsum + CR + FYM, RNPK + Gypsum + FYM and RNPK + FYM treatments by 31%, 28% and 26%, respectively (Table 2). Gypsum application promoted aggregation by providing of exchangeable $Ca^{2+}$ thereby reducing clay swelling, resulting in increased aggregate stability and reduced soil crusting (Zhao *et al.,* 2019; Manna *et al.,* 2019). Soil biological properties such microbial biomass carbon (MBC) and dehydrogenase (DHA) activity significantly improved in organic amendments applied solely and combined with gypsum. This increase in microbial activity is due to availability of carbon rich materials such as FYM, CR alongwith plant biomass, root exudates etc. which release organic acids upon decomposition and provide substrate for microbial activity in root zone of crops (Bello *et al.,* 2021). Organic amendments significantly increase C and N content, which stimulates enzyme activity and enhances microflora diversity in the soil (Turmel *et al.,* 2015). Further, integration of organic amendments enhances carbon content which bound soil particles, improve soil structure and water stability aggregates, thus reducing soil and nutrient loss as compared to unamended plots.

## 4. CONCLUSIONS

The study evaluated the effect of various combinations of organic and inorganic amendments on natural resource conservation, crop productivity and soil properties in soybean-mustard cropping system of semi-arid regions. Maximum conservation of natural resources was observed in combined application of amendments which reduced surface runoff (38%) and soil loss (52%) compared to control treatment in soybean crop. Average nutrient losses were significantly high under control plots without amendment application. Study result demonstrated that combined application of amendments RNPK + Gypsum + CR + FYM produced least loss of all nutrients and SOC, suggesting a strong basis of incorporating amendments in soil management practices to reduce soil fertility deterioration through erosion in semi-arid regions of western India. Application of organic amendments and gypsum reduced ESP, improved MWD, SOC, available sulfur content, and enhanced microbial properties. Consequently, we found that improved soybean and mustard yield under RDF + Gypsum + CR, RDF + Gypsum + CR + FYM, RDF + Gypsum + CR treatment compared to control without amendments. Similarly, higher mustard equivalent yield was observed in treatments with conjunctive use of gypsum with organic amendments due to reduced soil erosion and improved soil properties. Therefore, gypsum and organic amendment application with proper soil conservation approaches are recommended for controlling soil erosion, reducing nutrient loss, improving soil health and sustaining crop productivity under oilseed cropping sequence in degraded vertisol of western India.

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