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Raised bed with modified furrow system and supplemental irrigation for sustainable dryland agriculture in Alfisols of semi-arid India

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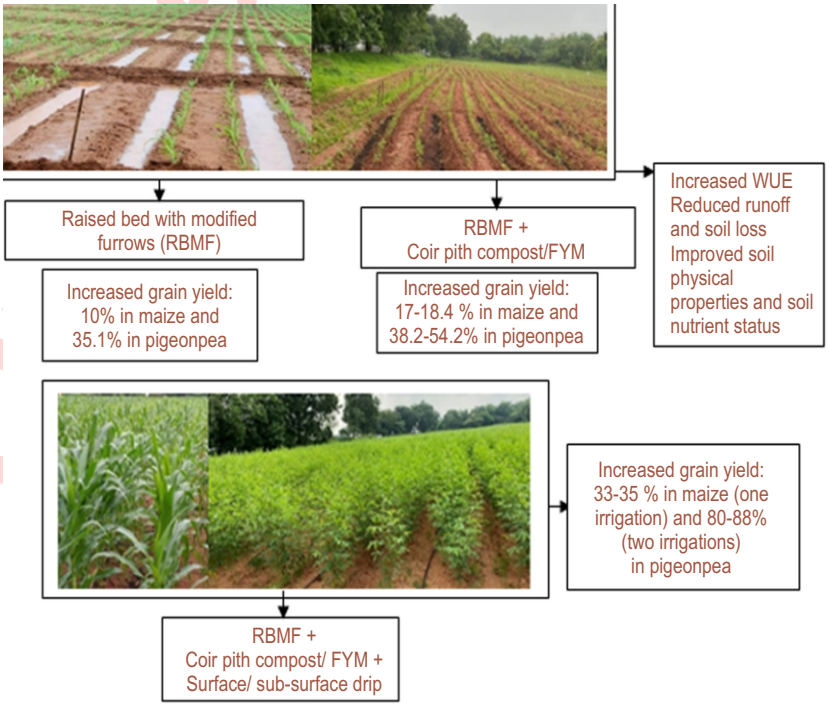
Abstract

Aim: To develop an improved rainwater harvesting technique for field crops in drylands, and to study its efficacy to promote moisture conservation, mitigate soil erosion, in order to enhance crop productivity and water use efficiency.

Methodology: This experiment was laid out in a strip-plot design with soil and water conservation (SWC) treatments and supplemental irrigation during 2021 to 2023 with maize -pigeonpea crop rotation. The SWC treatments were: M_1- Raised bed with modified furrow system (RBMF); M_2- RBMF with coir pith compost; M_3- RBMF with farmyard manure; M_4- RBMF with tank silt and M_5- Control (without raised bed/ Farmers practice). The irrigation treatments were: I_0-No irrigation (NI); I_1-With supplemental irrigation using sub-surface (10 cm) drip (SSDI) and I_2-With supplemental irrigation using surface drip (SDI) in three replications. Maize and pigeonpea was taken up in alternate years. The observations included soil physical and chemical properties, runoff, soil loss and grain yield.

Results: During normal year, RBMF with coir pith compost or farmyard manure in the furrows increased the grain yield in maize by 17.0-18.4% and pigeonpea yield by 38.2 -54.2%, respectively.These treatments improved the soil moisture by 2-3% (dry basis) and controlled soil loss by 55 to 60%. Along with these treatments, two irrigations increased the pigeonpea yield by 80-88% whereas one irrigation in maize increased the yield by 33-35%. Among irrigations, the sub-surface drip system resulted in more crop yield and higher water use efficiency (WUE) of 3.25 to 3.40 kg ha^{-1} mm^{-1} during the period of drought year.

Interpretation: RBMF along with coir pith compost or farmyard manure in the furrows had improved the soil moisture, reduced soil erosion, enhanced nutrient status of soil, crop productivity and water use efficiency considerably in the Alfisols.



RBMF system in maize and pigeonpea (normal year)

Key words: Alfisols, Drylands, Moisture conservation, Raised bed, Sub-surface drip, Supplemental irrigation

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Introduction

In India, most of the semi-arid regions receive an annual highly erratic rainfall ranging between 400 to 1000 mm and rainwater is the major water resource with limited groundwater (Reddy *et al.*, 2022). While precipitation is minimal in these regions, the amount of potential evapotranspiration exceeds the average annual rainfall resulting in water shortage leading to over-exploitation of groundwater. The uneven distribution of rainfall and prolonged dry spells during crop growing season results in severe moisture stress and reduces the crop productivity. Approximately, 33% of the soils in the semi-arid tropics are Alfisols, characterized by low productivity, low water holding capacity and are subjected to moderate or high soil erosion. Hence, appropriate soil management practices are needed to address these issues at the earliest and the widely adopted measures includes tillage, bed and furrow, ridge and furrow and biologically based systems. The renaissance of raised bed and furrow as soil nano tech for producing global food sufficiency for accomplishing sustainable development goal was reported by Yadav (2020). Raised bed planting increases the grain yield, and irrigation in alternate furrows can save water by 35% and water productivity by 50% (Sarkar *et al.,* 2019). Previous studies have reported that soil amendments like coir pith compost is an excellent organic manure which improves soil health and reduces soil erosion (Jana and Boxi, 2022). Also, farmyard manure without contamination can be applied directly to soil to improve the crop yield and soil quality (Chandra, 2021).

Application of soil amendments like tank silt to light textured soil improves the soil texture, nutrient status, increases the moisture holding capacity and crop productivity (Indoria *et al.,* 2016). In addition to this, providing two or three supplemental irrigations to crops during prolonged dry spells, in semi-arid regions can save crop and enhance crop yield by 40 to 80% (Srinivasarao *et al.,* 2017). Compared to normal drip, the sub-surface drip system ensures availability of water and nutrients directly to crop root zone (Mohammad *et al.,* 2014). The selected study area lies in semi-arid region with relatively low/erratic rainfall, experiencing prolonged dry spells during critical growth stages of the crops. Previous researchers have studied and reported the performance of in-situ water conservation technique, application of mulch and supplemental irrigation studies separately. In the present study, an attempt was carried out by integrating *in-situ* water conservation (raised bed with modified furrow system), application of materials like coir pith compost/ FYM/ tank silt and supplemental irrigation (drip) simultaneously to enhance the soil moisture conservation, mitigate soil erosion and enhance crop productivity and water use efficiency for dryland crops.

Materials and Methods

Study site and experimental details: The experiment was conducted at ICAR-Central Research Institute for Dryland Agriculture (CRIDA) Research Farm (17°23'N latitude, 78°29'E longitude at an elevation of 540 m above msl) at Hayathnagar, Rangareddy district of Telangana during 2021 to 2023 with maize -pigeonpea crop rotation. The mean annual rainfall ranged between 700 - 850 mm. The soil in the experimental site was Typic Haplustalf, soil order Alfisol and Hayathnagar series. The soil consisted 80.32% sand, 6.64% silt and 13.04% clay and was sandy clay loam in texture. During the experimental period, the mean seasonal rainfall was 794 mm, mean seasonal maximum and minimum temperature were 31.3°C and 21.2°C, respectively. This experiment was laid out in a strip-plot design with following treatments in three replications.

FACTOR A: 5 (Soil and water conservation): A_1- Raised bed with modified furrow system (25 cm deep furrow) (RBMF); A_2- RBMF with coir pith compost in the furrows; A_3- RBMF with farmyard manure in the furrows; A_4- RBMF with tank silt in the furrows and A_5- Control (without raised bed/ Farmers practice).

FACTOR B:3 (irrigation): B_0-No irrigation (NI); B_1-With supplemental irrigation using sub-surface (10 cm) drip (SSDI) during dry spells and B_2-With supplemental irrigation using surface drip (SDI) during dry spells.

Normally in raised bed with furrow system, a bed width of 90 cm, furrow width of 40 cm and furrow depth of 16 cm is followed and, in this case, furrow depth was modified to 25 cm. During first year, RBMF was made in the field with a raised bed planter developed at ICAR-CRIDA and from second year onwards, reshaping of bed and furrow system was done. There were 45 sub-plots of size 11.0 m x 6.0 m and the slope of sub-plots varied from 1 to 2.5%. Based on treatments, the furrows were filled up to 10 cm depth with moisture holding materials and the quantity of coir pith compost, FYM and tank silt applied were 3.0, 3.5 and 7.0 t ha^{-1}, respectively. Maize and pigeonpea rotation was taken up in alternate years with maize hybrid, DHM 117 sown on 10th July 2021, pigeonpea (TDRG-4 variety) on 23rd June 2022 and maize on 5th July 2023 depending on soil moisture. An integrated approach was attempted in this study using RBMF with supplemental irrigation to enhance the crop productivity.

Estimation of effective rainfall and irrigation requirement: Daily rainfall and temperature data collected from the experimental station during 2021-2023 and IMD data was used for the study. The mean annual rainfall during 1951-2023 was categorized into normal and drought years based on IMD criteria. The ET_0 was estimated by utilizing temperature and rainfall data. Even though FAO Penman-Monteith method was recommended as a sole standard method for ET_0 calculation (Allen *et al.,* 1998), based on the availability of data, the Hargreaves and Samani (1985) method was used in this study.

$$\lambda ET_0 = 0.0023 R_a T_d^{0.5} (T + 17.8) \quad \text{.....(1)}$$

where, R_a is the extra-terrestrial solar radiation ($MJm^{-2} d^{-1}$); T_d is the difference between daily maximum and daily minimum temperature (^0C); T is the mean temperature (^0C); λ is the latent heat of vaporization ($MJ\ kg^{-1}$) and ET_0 is the reference crop

evapotranspiration (mm day^{-1}). The crop evapotranspiration (ET_c) was calculated using Eq. 2

$$ET_C = k_c\, ET_0 \quad \text{..... (2)}$$

where, k_c is the crop coefficient that depends on the crop growth stages

$$GIR = \frac{ET_C - R_e}{\eta_p} \quad \text{..... (3)}$$

where, *GIR* is the gross irrigation requirement (mm); R_e is the10 days effective rainfall (mm); η_p is the application efficiency. R_e was estimated using empirical Eqns (4,5) developed at ICAR-CRIDA (Rejani *et al.,* 2020).

$$R_e = P(41.7 - 0.2P)/41.7 \quad \text{for } P \leq 83 \text{ ..... (4)}$$
$$R_e = 41.7 + 0.1P \quad \text{for } P > 83 \text{ ..... (5)}$$

where, P is the 10 days rainfall (mm). Thereafter, the crop water requirement and irrigation requirement for maize and pigeonpea was estimated. Since, drylands have limited water availability, supplemental irrigation was applied whenever the soil moisture dropped below 6% db, and the plants showed wilting.

Environmental implications: Conserving rainfall through RBMF has positive implications such as controlling erosion, enhances soil moisture content and soil nutrient status. Previous studies have reported the use of normalized difference vegetation index (NDVI) for drought monitoring (Sruthi *et al.,* 2015). In this study, NDVI was recorded using a hand held green seeker. The SPAD reading, which indicates the chlorophyll content in the leaves was measured during anthesis stage of maize crop. Runoff and soil loss were estimated from the data recorded using tipping bucket and infiltration rate using double ring infiltrometer. Soil moisture content was determined regularly by gravimetric method. Soil samples were collected from 0 to 15 and 16-30 cm depth prior to the experiment (2021) as well as after third crop harvest (2023) for nutrient analysis. Undisturbed soil samples were collected and bulk density of the soil was estimated. Soil pH was determined by potentiometric method and electrical conductivity using conductivity meter. The available nitrogen, available phosphorus, available K and extractable ions (Ext. Fe, Cu, Zn, Mn) were determined using standard procedure.

Crop productivity and water use efficiency: In order to evaluate the performance of developed technology on crop productivity and drought resilience, plot wise yield was recorded and analysed. The water use efficiency and rainwater use efficiency in different treatments were determined (Sharma *et al.,* 2013) using the equations below:

$$WUE = \frac{Y}{(P+I)} \times 100 \quad \text{.....(6)}$$

$$RWUE = \frac{Y}{P} \times 100 \quad \text{.....(7)}$$

Where WUE is the water use efficiency (kg ha^{-1} mm^{-1}), RWUE is the rain water use efficiency (kg ha^{-1} mm^{-1}), Y is the grain yield (kg ha^{-1}), P is the rainfall during crop season (mm) and I is the supplemental irrigation (mm).

Statistical analyses: The statistical analysis of data was performed using SAS software.For the analysis, Least Significant Difference was used to compare the Factor A (irrigation treatments) means and Factor B (Soil and water conservation treatments) means and Coefficient of Variation (CV) for comparing the interaction between B and A. The model structure for strip plot design was

$$Y_{ijk} = \mu + R_i + A_j + B_k + (RA)_{ij} + (RB)_{ij} + (AB)_{ij} + \in_{ijk} \quad \text{.....(8)}$$

where Y_{ijk} is the Observation; μ is the overall mean; R_i is the replication effect, A_j is the Factor A (strip factor 1); B_k is the Factor B (strip factor 2); $(RA)_{ij}$ is the Error term for A (main plot error); $(RB)_{ij}$ is the Error term for B; $(AB)_{ij}$ is the interaction between A and B; $\in_{ijk}$ is the Residual error.

Results and Discussion

During the normal year 2021 and 2022, the seasonal effective rainfall was less than seasonal evapo-transpiration rate (ET_0) (Table 1). This trend of ET_0 shows the need of irrigation requirement in crop season even in normal year, and the irrigation requirement for maize was 119.8 mm (2021) and pigeonpea was 48.6 mm (2022). Similarly, during drought year 2023, the seasonal ET_0 was very high (995.6 mm) resulted in severe moisture stress and higher irrigation requirement (245.9 mm in maize). Previous studies have also reported that higher evapo-transpiration rates and long crop duration resulted in increased irrigation requirement of crops (Hakami-Kermani and Babazadeh, 2026). Therefore, effective water conservation strategies, mulching and deficit irrigation practices needs to be implemented to enhance water retention (Reta *et al.,* 2024).

Even though 2021 was a normal year, prolonged dry spells of 22 days and 11 days duration occurred and one supplemental irrigation of 2.0 cm was provided to the maize crop during critical period coincided with 22 days dry spell. Similarly, in normal year 2022, prolonged dry spell occurred for 12 days and 49 days duration and the soil moisture was depleted to 4 to 6% during 49 days dry spell and the crops in raised beds was also affected. Hence, three irrigations of 2 cm each was given to pigeonpea crop in November and December. The year 2023 was a severe drought year and the first dry spell occurred for 11 days just after sowing and the second one lasted for 25 days in August. The maize crop was unable to withstand the second dry spell of 25 days even with *in-situ* moisture conservation and hence, three irrigations of 2 cm was provided in each week. Again, prolonged dry spells occurred for 9 days in September and another irrigation was given. Later, dry spell started from 30th September and continued till the end of the crop season. The soil moisture was depleted to 4 to 6% db in various treatments, and hence two more

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Table 1: Seasonal rainfall, effective rainfall, ET_0 (mm) and irrigation requirement (IR) during 1951 to 2023

Year	Rainfall - crop season (mm)	Effective rainfall - crop season (mm)	T max	T min	ET_0 (seasonal) (mm)	CWR maize (mm)	CWR pigeonpea (mm)	IR maize (mm)	IR pigeonpea (mm)
2021	1001.7	530.6	30.9	21.3	922.6	442.8	285.6	119.8	98.0
2022	936.6	555.8	31.0	21.0	937.8	434.4	285.6	110.5	48.6
2023	442.6	300.1	31.9	21.0	995.6	465.1	305.8	245.9	122.9

Table 2: Effect of RBMF and irrigation on NDVI, SPAD and leaf area of maize (2023)

Treatments	NDVI			SPAD	LEAF AREA (cm^2 $plant^{-1}$)
	24 July 2023	14 Aug 2023	6 Oct 2023		
Factor B					
SDI	0.58	0.64	0.59	48.09	2888.43
SSDI	0.62	0.68	0.62	49.34	3176.63
No irrigation, NI	0.60	0.64	0.53	38.09	864.82
LSD	NS	NS	0.045	3.117	314.9
Factor A					
RBMF+CP	0.62	0.67	0.60	49.27	2799.77
RBMF+FYM	0.66	0.70	0.63	46.46	2849.87
RBMF	0.61	0.65	0.58	45.27	2184.15
RBMF+TS	0.58	0.66	0.58	46.93	2220.27
Control	0.53	0.58	0.53	37.94	1495.75
LSD	0.042	0.034	0.039	2.947	360.0
Interactions (B x A)					
SDI x (RBMF+CP)	0.58	0.65	0.60	53.27	3588.82
SDI x (RBMF+FYM)	0.66	0.70	0.64	49.10	3683.76
SDI x RBMF	0.59	0.64	0.60	49.23	2864.54
SDI x (RBMF+TS)	0.57	0.64	0.59	53.73	2940.44
SDI x Control	0.52	0.58	0.53	35.10	1364.57
SSDI x (RBMF+CP)	0.62	0.69	0.66	54.17	3847.03
SSDI x (RBMF+FYM)	0.68	0.73	0.68	50.87	3930.71
SSDI x RBMF	0.63	0.67	0.62	48.60	2811.53
SSDI x (RBMF+TS)	0.6	0.68	0.61	48.47	2830.66
SSDI x Control	0.56	0.61	0.55	44.60	2463.23
NI x (RBMF+CP)	0.66	0.67	0.53	40.37	963.45
NI x (RBMF+FYM)	0.63	0.67	0.56	39.40	935.15
NI x RBMF	0.62	0.64	0.53	37.97	876.38
NI x (RBMF+TS)	0.58	0.65	0.53	38.60	889.70
NI x Control	0.51	0.55	0.50	34.13	659.44
CV	7.0	8.19	8.08	7.74	13.83

(Note: SDI - Surface drip irrigation; SSDI- Sub-surface drip irrigation; NI- No irrigation; RBMF- raised bed with modified furrow system; CP- Coir pith compost; FYM – Farm yard manure; TS- Tank silt)

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irrigations of 2 cm each was given.From the field observations, it was found that maize and pigeonpea crops grown on raised beds could withstand dry spells of nearly 10 days and 20 days, respectively. Earlier studies also reported raised bed system as a feasible water saving technology which reduces irrigation requirement (Munmun *et al.*, 2024; Adham *et al.*, 2026).

In this study, during drought year 2023, higher NDVI of 0.70 to 0.73 was obtained in August under RBMF with FYM/coir pith compost and supplemental irrigation whereas 0.55 was in unirrigated control. Subsequently, NDVI reduced due to drought conditions (Table 2). The chlorophyll content (SPAD) was also higher in sub-surface drip irrigation (49.34), followed by surface drip (48.09) and was lower in un-irrigated control (38.09). Among the treatments with moisture holding materials, the chlorophyll content was higher in coir pith compost treatment (49.3) and FYM treatment (46.5) and was least in control (37.9). Similar trend was observed in the leaf area of maize crop during anthesis (Table 2). Previous researchers also used NDVI and SPAD readings to study the impact of different levels of deficit irrigation

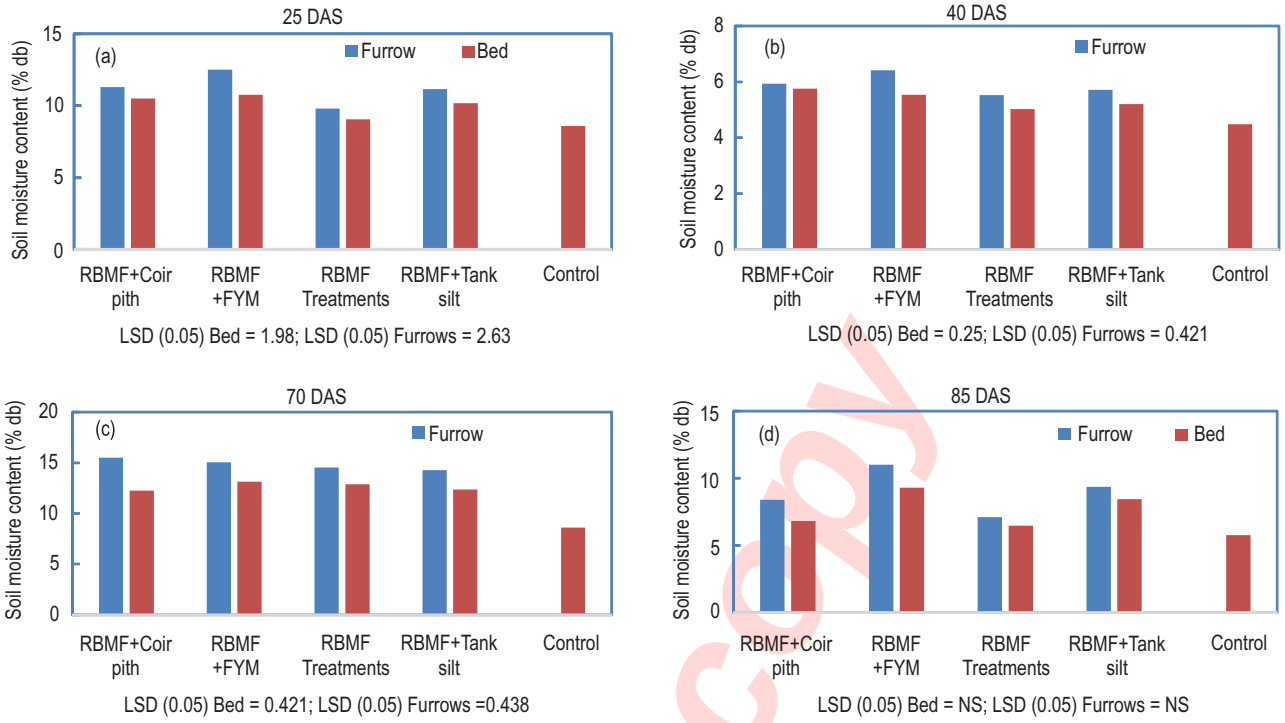


Fig. 1 (a-d): SMC during 25, 40, 70 and 85 DAS under different treatments in maize crop (2021).

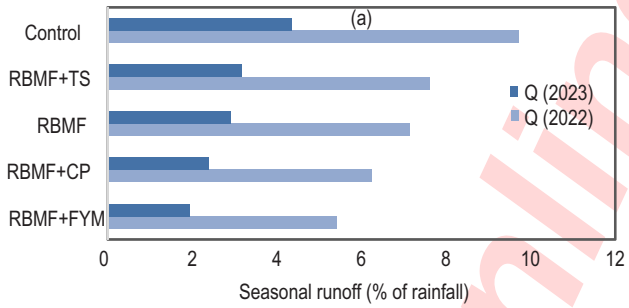


Fig. 2a: Effect of RBMF on runoff potential during normal and drought years.

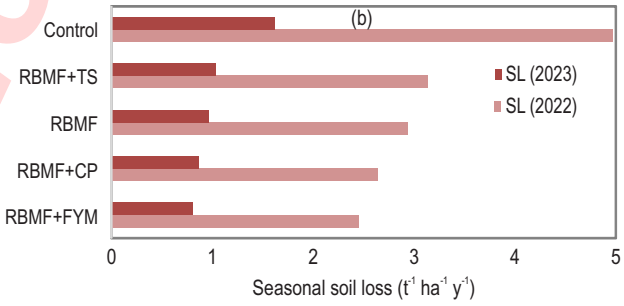


Fig. 2b: Effect of RBMF on soil loss during normal and drought years.

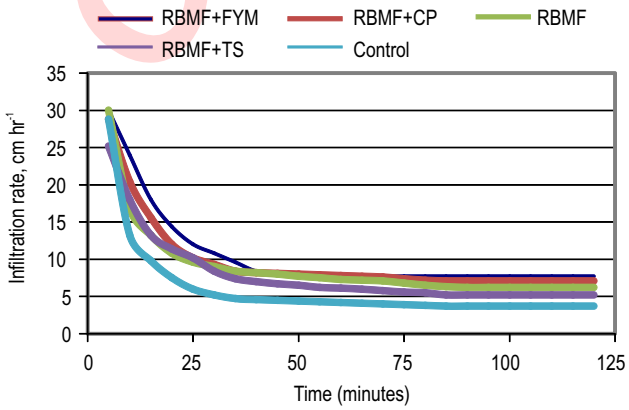


Fig. 3: Infiltration rate of the soil under different treatments.

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Table 3: Soil physical properties (initial) at the experimental site

Soil physical parameters	Soil depth (cm)	
	0-15	16-30
Soil texture	Sand-80.32%, Silt-6.64% and Clay-13.04%	Sand- 76.05%, Silt-7.06% and Clay-16.89%
Texture class	Sandy clay loam	Sandy clay loam
Bulk density (Mg m^{-3})	1.67	1.73
Soil total porosity (%)	37.06	34.90
Water content at -0.33 bar (% w/w)	12.57	13.25
Water content at -15 bar (% w/w)	4.52	4.38
Available water content (% w/w)	8.05	8.87
K_{sat} value (cm/min)	0.169	0.141

Table 4: AWC of moisture holding materials (soil amendments) used

Amendments	-0.33 bar % (w/w)	-15 bar % (w/w)	AWC % (w/w)
Farm Yard Manure (FYM)	44.9	6.1	38.8
Tank silt	21.7	4.4	17.3
Coir-pith compost	46.7	5.0	41.7

on soybean, and found that irrigation at 25% depletion of available soil moisture (DASM) during flowering and pod development stages resulted in higher NDVI and SPAD values compared to 50% and 75% DASM (Rajanna *et al.,* 2022).

During 2021 with maize crop, the soil moisture content (SMC) after 25, 40, 70 and 85 DAS in the beds and furrows was analysed (Fig. 1 a-d). The higher SMC, 25 DAS was on par in FYM (10.8%) and coir pith treatments (10.5%) whereas in RBMF, it was 9.1% and lowest in control (8.6%). Similar trend was observed at 40, 70 and 85 DAS. No considerable variation in SMC was observed in tank silt and raised bed treatments. Similarly, in normal year 2022 with pigeonpea crop, the SMC was recorded at 50, 90, 125 and 150 DAS. The higher SMC during 50 DAS was on par in FYM (10.9%) and coir pith treatments (10.25%), and was lowest in control (6.83%). Similar trend was observed during 90, 125 and 150 DAS. During the drought year 2023, soil moisture content normally ranged from 6-8% and it depleted below 5% several times and the crop in control was severely affected. Whereas, in treatments with moisture holding materials and supplemental irrigation, the plants recovered immediately after irrigation and hence, the plants were only slightly affected. Findings from previous study also revealed that integration of drip irrigation, mulching and raised bed system have favourable impact on soil–plant environment (Narjary *et al.,* 2026).

In normal year 2022, RBMF with FYM and coir pith compost reduced the runoff to 5.41 and 6.24% of seasonal rainfall compared to 9.71% in control. Similarly, these two treatments reduced the soil loss by 50 and 46% of control. During 2023, a lower runoff of 1.93% and 2.39% was observed in these two treatments and higher runoff of 4.35% was in control (Fig. 2a). Similarly, soil loss was reduced by 48.0 to 51.5% in RBMF with coir pith compost/FYM compared to control (Fig. 2b). Previous studies also reported that raised bed system reduced the surface runoff by 15–20 mm in Alfisols and the runoff was less than 2% of total rainfall (<500 mm) in drought year and reduced the soil loss by 30–60% compared to flat beds, which is on par with the results obtained in the present study (Garg *et al.,* 2022).

The soil texture of the site was sandy clay loam and the field capacity (FC) of soil prior to the experiment was 12.57 and 13.25% and wilting point (WP) was 4.52 and 4.38% at 0-15 and 16-30 cm depths. The available SMC ranged from 8 to 9% (w/w) (Table 3). The available water content (AWC) was higher in coir pith compost (41.7% w/w) followed by FYM (38.8%) and tank silt (17.3%) (Table 4). Therefore, among the selected materials, coir pith compost and FYM are the most suitable materials for enhancing the moisture holding capacity of soil. Previous studies have also reported that coir pith is in high demand in dry areas due to high moisture retaining capacity of about 40% (Jana and Boxi, 2022). RBMF with FYM and coir pith compost decreased the bulk density, increased the porosity and AWC of soil (Table 5). There was no significant impact on the mean weight diameter (MWD) of soil, saturated hydraulic conductivity (Ksat), FC, WP and AWC in irrigation treatments whereas an improvement in MWD, Ksat and AWC was found. Also, a marginal increase in OC, available N, available P and micro-nutrients like Cu, Zn, Fe and Mn was found in RBMF with FYM and coir pith compost treatments (Table 6). Previous studies have also reported that application of coir pith on long term basis could reduce bulk density, increase the porosity and water holding capacity (WHC), OC and potassium content of soil (Thomas *et al.,* 2013; Lin *et al.,* 2023). Similarly, higher infiltration rate of 7.7 cm hr^{-1} was observed in RBMF with FYM, followed by coir pith compost with

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Table 5: Effect of raised bed with modified furrow system and supplemental irrigation on soil physical properties (2023)

Treatments	Porosity (%)	Bulk density (Mg m^{-3})	MWD (mm)	Ksat (cm min^{-1})	AWC % (w/w)	WP % (w/w)	FC % (w/w)
Factor B							
SDI	39.04	1.61	1.294	0.168	8.82	4.43	13.25
SSDI	40.30	1.58	1.297	0.174	8.93	4.42	13.35
No irrigation, NI	36.81	1.67	1.290	0.174	8.69	4.43	13.12
LSD	1.457	0.031	NS	NS	NS	NS	NS
RBMF+CP	39.50	1.60	1.344	0.173	8.94	4.47	13.41
RBMF+FYM	40.80	1.57	1.350	0.179	9.41	4.42	13.82
RBMF	38.16	1.64	1.259	0.171	8.65	4.42	13.07
RBMF+TS	38.11	1.64	1.261	0.174	8.91	4.38	13.29
Control	37.02	1.67	1.255	0.161	8.16	4.45	12.61
LSD	1.219	0.039	0.017	0.008	0.375	NS	0.400
SDI x (RBMF+CP)	39.87	1.59	1.347	0.171	8.98	4.51	13.48
SDI x (RBMF+FYM)	41.01	1.56	1.349	0.175	9.43	4.41	13.84
SDI x RBMF	38.74	1.62	1.258	0.163	8.63	4.44	13.07
SDI x (RBMF+TS)	38.62	1.63	1.257	0.174	8.88	4.37	13.25
SDI x Control	36.98	1.67	1.257	0.157	8.17	4.44	12.60
SSDI x (RBMF+CP)	41.38	1.55	1.348	0.174	9.07	4.50	13.58
SSDI x (RBMF+FYM)	42.89	1.51	1.359	0.184	9.67	4.46	14.13
SSDI x RBMF	39.87	1.59	1.262	0.176	8.77	4.42	13.19
SSDI x (RBMF+TS)	39.48	1.60	1.266	0.176	8.96	4.40	13.37
SSDI x Control	37.86	1.65	1.252	0.158	8.17	4.31	12.48
NI x (RBMF+CP)	37.23	1.66	1.337	0.175	8.78	4.39	13.17
NI x (RBMF+FYM)	38.49	1.63	1.342	0.178	9.12	4.38	13.50
NI x RBMF	35.85	1.70	1.257	0.174	8.55	4.40	12.95
NI x (RBMF+TS)	36.23	1.69	1.260	0.174	8.88	4.36	13.25
NI x Control	36.22	1.69	1.256	0.168	8.14	4.60	12.75
CV	**3.42**	**2.10**	**0.87**	**11.72**	**3.93**	**4.85**	**3.0**

7.1 cm hr^{-1} and was lower in control (3.7 cm hr^{-1}). Overall, an improvement in the nutrient status of soil was observed in the moisture conservation (RBMF) treatment with moisture holding materials.

During normal year 2021, RBMF in maize increased the grain yield by 10.0% compared to unirrigated control (2.06 t ha^{-1}) (Table 7). On adding FYM/ coir pith compost, the grain yield increased by 17.0-18.4% and one supplemental irrigation increased the yield by 28-35%. The impact of dry spell was mild in 2021 and hence, no considerable variation in yield was observed in surface and sub-surface drip plots. In normal year 2022, RBMF increased the grain yield by 35.1% and addition of FYM and coir pith compost increased the yield by 54.2% and 38.2% respectively. In addition to this, two irrigations using surface drip increased the pigeonpea yield by 73.3 to 79.4% and sub-surface drip increased the yield by 80.9 to 88.5%, respectively, compared to unirrigated control (1.31 t ha^{-1}). During drought year 2023, raised bed with furrows increased the grain yield of maize by 31.8% compared to unirrigated control (0.44 t ha^{-1}). RBMF with moisture holding materials increased the grain yield considerably and with six supplemental irrigations, the maize yield in best treatments was 2-3 times higher than unirrigated control (Table 7). Previous studies have also reported that raised bed sowing of pigeonpea in dryland areas enhanced the grain yield by 23% and 32% in stress and normal year (Singh *et al.,* 2022). Adoption of raised beds of optimal size across South Asia, North Africa and West Asian drylands saved 25 to 40% water and improved the cereal yields (Adham *et al.,* 2026). Similar trend was observed with respect to WUE, and the highest WUE of 3.25 to 3.40 kg ha^{-1} mm^{-1} was observed in drought year under sub-surface drip system in maize crop. Previous studies have also reported improved water use efficiency, under raised bed system especially in drought prone regions (Latif and Abbas, 2025).

In semi-arid regions with limited rainfall, adoption of *in-situ* moisture conservation techniques is the need of the hour. Along with *in-situ* moisture conservation, application of moisture holding materials can further enhance the soil moisture retention, control soil erosion and improve the soil health. In case of prolonged dry spells, supplemental irrigations through sub-surface drip system can enhance the crop yield considerably. Therefore, an integrated approach comprising of in-situ water conservation (RBMF), application of coir pith compost/FYM and supplemental irrigation (drip) simultaneously is essential to enhance crop productivity and water use efficiency for dryland crops.

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Table 6: Effect of raised bed with modified furrow system and supplemental irrigation on nutrient status of soil (2023)

Treatments	OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available Cu (mg kg^{-1})	Available Zn (mg kg^{-1})	Available Fe (mg kg^{-1})	Available Mn (mg kg^{-1})
Factor B								
SDI	0.42	129.16	14.52	122.82	1.03	0.40	9.01	8.74
SSDI	0.43	133.39	15.64	133.16	1.03	0.42	8.99	8.98
No irrigation, NI	0.42	124.87	11.07	118.84	0.91	0.38	8.56	8.51
LSD	NS	6.611	0.527	NS	0.077	0.012	0.348	0.136
Factor A								
RBMF+CP	0.44	144.92	16.23	129.96	1.13	0.42	7.81	9.85
RBMF+FYM	0.45	139.43	14.99	128.32	0.99	0.40	9.26	9.16
RBMF	0.42	118.56	13.30	121.41	1.05	0.37	9.20	9.30
RBMF+TS	0.41	132.39	14.47	124.26	0.98	0.46	9.84	8.01
Control	0.41	110.40	9.73	120.76	0.82	0.35	8.16	7.40
LSD	0.009	6.200	0.881	NS	0.101	0.026	0.182	0.221
Interactions (B x A)								
SDI x (RBMF+CP)	0.43	139.93	16.23	125.97	1.12	0.40	8.20	9.74
SDI x (RBMF+FYM)	0.44	140.43	16.33	130.18	1.02	0.40	9.33	9.17
SDI x RBMF	0.41	121.53	14.13	110.90	1.08	0.39	9.33	9.35
SDI x (RBMF+TS)	0.41	132.80	15.20	125.37	1.01	0.46	9.83	8.02
SDI x Control	0.40	111.10	10.70	121.67	0.90	0.35	8.33	7.43
SSDI x (RBMF+CP)	0.44	150.67	19.00	136.80	1.21	0.44	7.85	10.20
SSDI x (RBMF+FYM)	0.46	146.10	17.07	131.78	1.05	0.41	9.47	9.37
SSDI x RBMF	0.42	119.83	14.50	146.13	1.03	0.38	9.47	9.52
SSDI x (RBMF+TS)	0.41	136.47	16.57	126.83	1.01	0.50	9.97	8.22
SSDI x Control	0.41	113.90	11.07	124.27	0.87	0.37	8.20	7.57
NI x (RBMF+CP)	0.43	144.17	13.47	127.10	1.04	0.41	7.38	9.63
NI x (RBMF+FYM)	0.43	131.77	11.57	122.98	0.89	0.38	8.97	8.92
NI x RBMF	0.41	114.30	11.27	107.20	1.03	0.35	8.80	9.02
NI x (RBMF+TS)	0.40	127.90	11.63	120.57	0.91	0.43	9.73	7.79
NI x Control	0.41	106.20	07.43	116.33	0.70	0.34	7.93	7.20
CV	**2.55**	**3.52**	**2.52**	**11.31**	**7.28**	**2.85**	**2.03**	**0.959**

Table 7: Effect of RBMF and supplemental irrigation on yield of maize and pigeonpea (2021-2023)

Treatments	Yield (t ha^{-1})			WUE (kg ha^{-1} mm^{-1})		
	2021 (maize)	2022-23 (pigeonpea)	2023 (maize)	2021 (maize)	2022-23 (pigeonpea)	2023 (maize)
Factor B						
SDI	2.49	2.14	1.56	2.24	1.90	2.78
SSDI	2.55	2.19	1.66	2.29	1.95	2.96
No irrigation, NI	2.30	1.75	0.64	2.13	1.64	1.45
LSD	NS	0.185	0.072	NS	NS	0.139
Factor A						
RBMF+CP	2.60	2.15	1.41	2.34	1.94	2.64
RBMF+FYM	2.62	2.28	1.50	2.39	2.05	2.81
RBMF	2.34	1.96	1.19	2.13	1.77	2.22
RBMF+TS	2.42	1.98	1.25	2.20	1.79	2.32
Control	2.24	1.76	1.07	2.04	1.58	1.99
LSD	0.167	0.227	0.061	0.149	0.208	0.119
Interactions (B x A)						
SDI x (RBMF+CP)	2.65	2.27	1.67	2.39	2.02	2.98
SDI x (RBMF+FYM)	2.64	2.35	1.80	2.38	2.08	3.21
SDI x RBMF	2.37	2.04	1.49	2.13	1.81	2.67
SDI x (RBMF+TS)	2.46	2.04	1.50	2.22	1.81	2.68
SDI x Control	2.33	1.99	1.33	2.1	1.77	2.37

Table continued.

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SSDI x (RBMF+CP)	2.74	2.37	1.82	2.47	2.1	3.25
SSDI x (RBMF+FYM)	2.79	2.47	1.91	2.51	2.19	3.41
SSDI x RBMF	2.38	2.07	1.50	2.14	1.84	2.68
SSDI x (RBMF+TS)	2.48	2.08	1.62	2.23	1.85	2.89
SSDI x Control	2.34	1.97	1.45	2.11	1.75	2.59
NI x (RBMF+CP)	2.41	1.81	0.75	2.15	1.69	1.7
NI x (RBMF+FYM)	2.44	2.02	0.80	2.28	1.89	1.82
NI x RBMF	2.27	1.77	0.58	2.12	1.66	1.32
NI x (RBMF+TS)	2.31	1.83	0.62	2.16	1.72	1.40
NI x Control	2.06	1.31	0.44	1.92	1.22	1.00
CV	**6.23**	**11.29**	**3.89**	**6.17**	**10.87**	**3.92**

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