

Rain water harvesting, agroforestry and goat based intensification for livelihood resilience in drought prone rainfed smallholder farming system – a case for semi-arid tropics

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Research Article

Keywords: Rainfed farming system, Rain water harvesting, agroforestry, intensification, Livelihood, Resilience

Posted Date: January 10th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2450169/v1>

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Agroforestry Systems on June 24th, 2023. See the published version at <https://doi.org/10.1007/s10457-023-00863-x>.

Abstract

Rainfed areas are the home of millions of resource poor farmers whose livelihood is under continuous threat due to frequent droughts. Assuring double cropping and imparting livelihood resilience to rainfed small holders is a challenge. A study was planned in this direction during 2013–2021 for livelihood resilience and sustainable intensification of rainfed small holder farming systems through rain water harvesting and agroforestry based interventions. The one hectare rainfed farming system model comprising of rain water harvesting farm pond (25 m x 20 m x 2.5 m), less water requiring food crops (groundnut–barley and sorghum–chickpea), agrihorticulture [*Ziziphus mauritiana*+ (*Sesamum indicum*–*Cicer arietinum*)], silvipasture (*Leucaena leucocephala* + Tri-species hybrid grass + *Stylosanthes hamata*) and boundary plantation (*Leucaena leucocephala* and *Opuntia ficus-indica*) was evaluated at on-station as well as promoted on-farm. The goat rearing potential of the above model was also estimated under intensive and semi-intensive systems.

The on-station rainfed farming system module produced 4979 kg ha⁻¹ barley equivalent yield consisting of multiple products like barley, chickpea, groundnut, Indian jujube fruits, sesame, fodder (sorghum, TSH, *Stylosanthes*, *Leucaena* dried leaf meal and spine-less fodder cactus cladodes) and *Grewia* fruits and resulted in 709 US\$ year⁻¹ net returns with a benefit cost ratio of 2.1. The carrying capacity of the above model was found to be 9 and 35 goat year⁻¹ under intensive and semi-intensive rearing systems, respectively. The net returns increased by 26 and 89% with the inclusion of goat under intensive (US\$ 892) and semi-intensive rearing system (US\$ 1340), respectively in the rainfed farming system model. It was evident from the study that inclusion of goat, agroforestry and farm pond for rain water harvesting in the rainfed farming have resulted in higher profitability and resilience to less rainfall and its aberrations. Contrarily, the on-farm observations revealed that farmers could not take winter season crops without rain water harvesting. The rain water harvesting proved to be the key for reducing chances of crop failures due to droughts, ensuring double cropping (cropping intensity up to 200%) and sustainable intensification in rainfed areas. It can be concluded from the present study that intervention of water harvesting, agroforestry and goat in rainfed farming systems could enhance the farm productivity and profitability and impart resilience to the livelihood of rainfed farmers in semi-arid tropics.

Introduction

Globally, rainfed agriculture accounts for 79% of crop lands consisting of 95% in sub-Saharan Africa; 90% in Latin America; 75% in the Near East and North Africa; 65% in East Asia; and 60% in South Asia (FAO, 2021). Rainfed areas have special significance in terms of ecology, farm productivity and livelihood for millions of resource poor farmers and livestock keepers especially in arid and semi-arid tropics (Wani et al. 2009). Rainfed agriculture occupies about 51.2 percent of India's net cropped area (140 m ha), contributes 44% to the total food basket and supports nearly 40% population (Anonymous, 2021). The rainfed agro-ecosystems of India is characterised by high livestock and human population pressure, poverty, rapidly degrading natural resources (soil and water), very low crop productivity (1-1.5 Mg/ha) and rain water use efficiency (35–45%) for crop production (Palsaniya et al. 2012a). Agriculture in rainfed areas is a crop-livestock mix, highly complex, diverse (Palsaniya et al. 2009) and risk prone due to vagaries of monsoon (Palsaniya et al. 2011). A majority of the rainfed farmers in India are marginal and smallholders (86.2%), resource poor, practice subsistence type of agriculture (Bisht et al. 2020) and highly vulnerable to both short-term dry spells and long-term droughts (Rai et al. 2014). Moreover, changing rainfall patterns due to climate change may further compound the problems of rainfed farmers by intensifying dry spells and water scarcity. Contrary to this, if managed properly, rainfed areas have tremendous potential to contribute a larger share in global food basket and faster agricultural growth compared to the irrigated areas which have reached a plateau (Wani et al. 2009).

Rain water harvesting cum efficient recycling and agroforestry based intensification offer a great opportunity for enhancing productivity, natural resource conservation, risk proofing and sustaining livelihood of rainfed farmers (Palsaniya et al. 2012b). Rain water harvesting through farm ponds and its efficient recycling through drip and sprinkler systems as supplementary irrigation is useful in minimising the chances of crop failures during short-term dry spells (Palsaniya et al. 2012a). Similarly, adoption of agroforestry through including perennial components like fruit trees, fodder trees/shrubs, perennial grasses in land use also minimize risk as perennials are less affected by droughts and other weather vagaries (Palsaniya et al. 2010). Inclusion of animal components in such farming systems may further improve the profitability and resilience of the production system. Adoption and investments in rain water harvesting and agroforestry techniques are, therefore, important ways for decreasing risk and ensuring livelihood resilience in rainfed agriculture.

However, despite the ample importance and scope, the adoption rates of water-harvesting techniques and agroforestry in rainfed farming system mode are low. The systematic information on water harvesting – crop – agroforestry – animal integration under rainfed situation is scanty and therefore, need to be researched upon. Small ruminants (sheep and goat) play an important role in the livelihood of rainfed farmers. Small ruminants are raised under intensive (stall feeding) and semi-intensive (partial stall feeding and partial grazing) systems in rainfed areas (Mahanta et al. 2012; Shivakumara and Siddaraju 2019). There is also a need of exploring and calculating the carrying capacity potential and possible economic benefits of such rainfed models under stall feeding and semi-intensive animal rearing systems. Therefore, the present investigation was carried out to know the impact of rain water harvesting and agroforestry based intensification on livelihood resilience of rainfed smallholder farming systems of India. The hypothesis of this study was to ascertain whether integration of rainwater harvesting and

agroforestry would increase the productivity, profitability and resilience of rainfed farmers. It was also intended to know that such integration would enhance the potential of animal rearing eventually leading to increased farmer's livelihood and resilience.

Materials And Methods

Site characteristics

The field experiment was carried out at the Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute, Jhansi (Uttar Pradesh), India during 2014–2018. The latitude, longitude and altitude of the site were 25°27' N, 78°35' E and 271 m, respectively. The area received 652, 713, 827, 486 and 1055 mm rainfall during 2014, 2015, 2016, 2017 and 2018, respectively. The corresponding rainy days were 45, 48, 48, 35 and 43. The soil of the site was red in colour, sandy loam in texture, normal in pH (7.6), low in available N (131 kg ha⁻¹) and available K (190 kg ha⁻¹) and medium in available P (15.9 kg ha⁻¹) and soil organic carbon (0.58%). The electrical conductivity of the soil was 0.34 mmho cm⁻¹.

Module of interventions

The average land holding size in the study area is 1.08 ha. Therefore, one ha farming system model was developed with different components (water harvesting pond, rainfed crops, agrihorticulture, silvipasture, boundary plantation) as shown in Table 1 and described below.

Table 1
Components of the rainfed farming system

Enterprise	Area (ha)	Component (ha)	
		Rainy season	Winter season
Food crops	0.55	Groundnut (0.3)	Barley (0.3)
		Sorghum (0.25)	Chickpea (0.25)
Silvipasture	0.2	<i>Leucaena</i> + Tri-species hybrid grass + <i>Stylosanthes</i>	
Agrihorticulture	0.2	Indian jujube + (Sesame – Chickpea)	
Boundary plantation	-	<i>Leucaena</i> and spineless fodder cactus	
Rain water harvesting pond	0.05 (20 m × 25 m × 2.5 m)	<i>Grewia asiatica</i> on pond dykes	
Total	1.0		

Rain water harvesting pond

An earthen farm pond of 25 m × 20 m × 2.5 m dimension was constructed to harvest and store approximately 1.25 × 10⁶ litres of rainwater. The harvested rainwater was used for taking up different farming components through a sprinkler irrigation system.

Agrihorticulture [*Ziziphus mauritiana* + (*Sesamum indicum* – *Cicer arietinum*)]

The *Ziziphus mauritiana* (also known as Ber or Indian jujube) based agrihorticulture block was planted in 0.2 ha area at 6 m × 6 m spacing (row to row × plant to plant) and Sesame (*Sesamum indicum*) and chickpea (*Cicer arietinum*) were taken as intercrops during rainy and winter season, respectively. Grafted Indian jujube sapling of *Gola*, *Umrani* and *Seb* varieties were procured from ICAR-Central Arid Zone Research Institute, Jodhpur (Rajasthan) and planted in well prepared pits of 50 cm × 50 cm × 50 cm size during the rainy season. Sesame and chickpea were sown during the first week of July and first fortnight of October, respectively in the interspaces of Indian jujube. Both the crops were grown purely under rainfed condition with the recommended agronomic package of practices.

Silvipasture (*Leucaena leucocephala* + Tri-species hybrid grass + *Stylosanthes hamata*)

A silvipasture module consisting of *Leucaena leucocephala* + Tri-species hybrid grass + *Stylosanthes hamata* was established in 0.2 ha area. Hedge rows of *Leucaena leucocephala* were planted at 6 m row to row and 50 cm plant to plant spacing. Rooted slips of tri-species hybrid (TSH) grass (a cross of three species of genus *Pennisetum*, viz., *purpureum*, *glaucum* and *squamulatum*) were planted on both the sides of *Leucaena* hedge rows at 50 cm distance with 50 cm plant to plant spacing. *Stylosanthes hamata* seeds were sown in the remaining 5 m interspaces. All the components of silvipasture components were established during the rainy season and raised completely under rainfed condition with recommended package of practices.

Cropping systems

In the study, low water guzzling rainfed crops were selected for the system. The rainfed food crop component was taken in 0.55 ha area which consisted of groundnut – barley (0.3 ha) and sorghum – chickpea (0.25 ha) cropping systems. Groundnut and sorghum were sown after onset of rainfall during the first fortnight of July during the rainy season and maintained completely under rainfed condition. The winter season crops (chickpea and barley) were sown during the second fortnight of October on the conserved soil moisture. The winter crops were provided one or two need based irrigations from the water harvested in farm pond through a sprinkler system. These crops were grown with the recommended package of agronomic practices. The study of water balance is useful in establishing the length of growing season, optimum time of sowing and irrigation scheduling in a given climate. The components are useful in the monitoring of supplemental irrigation. The term balance relates to the moisture added through precipitation or irrigation and lost through ET, runoff and drainage and thereby it explains the change in water content of the soil profile. Thus it integrates climate with soil and crop. In the present study, Thornthwaite and Mather (1955) model is used to compute several parameters such as actual evapo-transpiration (AET), surplus (S), deficit (D), moisture adequacy Index (MAI) and soil moisture index (SMI). The storage capacity of soil is considered as 140 mm which was computed based on field capacity (15.5%), wilting point (6.2%), specific dry unit weight of soil (1.37g/cc) and rooting depth (105 cm). Actual rainfall and normal PET was taken into consideration to compute above water balance component. The crop water requirement/moisture adequacy index (MAI) for chickpea for the present study during its different growth stages was taken as ≥ 0.25 for seedling stage (3 weeks), ≥ 0.45 for vegetative (4 weeks), ≥ 0.60 for reproductive (5 weeks), ≥ 0.45 for physiological maturity (4 weeks) and ≥ 0.25 for harvest maturity stage (2 weeks) (Reddy 1993).

Boundary plantation

Leucaena leucocephala and spineless fodder cactus (*Opuntia ficus-indica*) were planted on the boundary of the one hectare farming system model. *Leucaena* and cactus were planted at 1 m plant to plant distance and maintained as hedge row and regularly harvested at 1.5 m height to get additional fodder as and when needed. Similarly, *Grewia asiatica* was planted on pond dykes at 2 m plant to plant distance to get fruits, fodder and twigs.

Goat production potential

Small ruminants, especially goats are the important component of the rainfed farming systems in semi-arid tropics. Inclusion of goats in the rainfed farming system may further enhance the profitability and reduce the associated risk. Therefore, the goat production potential was estimated for the studied rain water harvesting and agroforestry based farming system model. The carrying capacity and possible economic benefits were estimated by assuming two small ruminant rearing scenarios, i.e., intensive and semi-intensive systems. The animals are stall-fed under intensive system while they are taken for grazing in community and fallow lands and partially supplemented under semi-intensive system.

The goat carrying capacity and production potential scenario for the above rainfed farming system model was estimated by calculating the dry matter (DM) available from this system and assessing the per goat requirements of DM as per the standards available (ICAR, 2013). Two scenarios (intensive and semi-intensive) were assumed and goat carrying capacity was calculated by dividing the available total DM from the system by the required DM of one growing goat (15–38 kg body weight) for a period of 12 months. In an intensive system, the animals were completely stall-fed on cultivated feed and fodder, crop residues available from the integrated farming system model and were maintained indoors. In a semi-intensive system, the animals were allowed to graze for 6–7 hours daily. In a semi-intensive system, the availability of nutrients from grazing was calculated as per Mahanta et al. (2012). The goat carrying capacity for semi-intensive grazing system was calculated based on the finding that 1% DM requirement of the animal is supplemented from the model and remaining met from the grazing in common property grazing resources (CPGRs) and private fallow lands (Mahanta et al. 2012). In both the systems, nutrient requirement and daily body weight gain were estimated as per the standards described in ICAR (2013). The surplus and other non-edible produce from the rainfed farming system model were sold. It is assumed that goat kids with 15 kg body weight were included in the system and their body weight gains were calculated @ 70 g/day as per the findings reported in ICAR (2013). The animals were disposed of after attaining 38 kg body weight. The meat yield was calculated at 50% dressing rate (i.e., 50% meat yield of total body weight) and meat was sold @ Indian Rupees 600 kg⁻¹ meat. The returns from manure and skin were also included while calculating the economics of the systems. The expenditure on different parameters used in rearing and upkeep of animals was calculated as per the values suggested by Shivakumara and Siddaraju (2019).

On-farm survey

The farmers were also encouraged simultaneously to adopt rainfed farming system activities. A large number of farmers from surrounding areas of ICAR-IGFRI, Jhansi were exposed to rain water harvesting, agroforestry, goatry, etc in farming system mode during their visits to the institute under various capacity building programmes like trainings, field days, farmers' fairs, exhibitions, etc. A field survey was conducted during 2021 to collect information on profitability and resilience of above activities using a well structured questionnaire performa. Eighty five farmers practicing rainfed farming were selected from Jhansi district of Uttar Pradesh (seven villages - Sakrar, Ambabai, Birdha, Amarpur,

Palinda, Parwai and Lakara), Niwari district (four villages – Ghisalni, Hathiwar, Parasari, Rajapur), Tikamgarh district (three villages – Kurrai, Nandanpur, Kant) and Datia district (one village Garera) of Madhya Pradesh for the survey. The detailed profile of the selected farmers is described in Table 5.

Methods

The one ha module with above components was developed and continued for four years (2014–2018). The life cycle assessment and process analysis approach was used in the present study (Jones 1989; Jianbo 2006; Palsaniya et al. 2021). A detailed inventory of inputs and outputs of all the components of the rainfed farming module was maintained. The sun dried harvests from each component were threshed, winnowed and finally weighed after 15–20 days of harvesting. The final produce from individual components (grains, fruits, straw/stover, green fodder, etc) was recorded. The barley equivalent yield (BEY) was calculated to compare system performance by converting the yield of non-barley crops or components into equivalent barley yield on a price basis, using equation number (1).

$$BEY = \frac{Yield\ of\ non\text{--}barley\ component(kg) \times Price\ of\ non\text{--}barley\ component\ (Indian\ Rupee\ kg^{-1})}{Price\ of\ barley\ (Indian\ Rupee\ kg^{-1})} \text{ --- (1)}$$

All the data were analyzed for their descriptive parameters for mean, range and standard error (SE) by using SPSS software (version 16.0). The production cost and returns from individual components were calculated using prevailing market prices of their respective inputs and outputs. The total cost was deducted from the gross return to calculate the net return while the benefit cost ratio (BCR) was calculated on gross return basis using Eq. (2).

$$BCR = \frac{Gross\ return}{Total\ cost} \text{ --- (2)}$$

Results

Rainfall pattern during the study period

Rainfall is the primary source of water and is the main consideration for raising crops particularly in rainfed condition. Annual and monthly rainfall distribution during the study period has been shown in Table 2. The maximum annual rainfall of 1053 mm was recorded in the year 2013, whereas minimum rainfall (508.6 mm) was recorded during 2017. Distribution of monthly rainfall showed that the highest amount of rainfall recorded in the month of July followed by August. In July month, maximum rainfall of 447.8 mm distributed in 17 rainy days was received during the year 2016 followed by the year 2013, which received rainfall of 437.2 mm in 24 rainy days. During the winter season (November to March) no rainfall was received during November and December month except in 2013. However, 2014 and 2015 received more than 100 mm of rainfall during January to March.

Table 2
Rainfall distribution (mm) during the study period

Year/Month	2014	2015	2016	2017	2018
January	53	32.4	8.4	25.8	0
February	66.6	16	0.4	22.2	9
March	6.2	52.4	7.8	0	0
April	16.6	6.6	5.2	0	9.2
May	10	2.5	23.6	42.6	7
June	81.8	67.2	140.6	48.6	89.8
July	164.8	215.2	447.8	169.6	330.8
August	86.8	285.2	177.6	108.2	416
September	174	16.6	13	90.4	191.2
October	0	34	0	0	0
November	0	3	0	0	0
December	0	4.4	0	1.2	0
Total	659.8	735.5	824.4	508.6	1053

Productivity and profitability of the model

The component yield, productivity and economics in rain water harvesting and agroforestry based improved rainfed farming system model are presented in Table 3. The food crops in the model consisted of groundnut, barley and chickpea, which on an average, produced 240, 1021 and 311 kg grain yield, respectively. Among the food crop components, the highest barley equivalent yield (BEY) was observed in barley (1021 kg) followed by chickpea (925 kg) and groundnut (718 kg). On an average of 4 years, 200 kg Indian jujube fruits, 81 kg sesame and 179 kg chickpea grain yield was produced from the agrihorticulture component in the model. The equivalent yield in terms of barley was the highest for chickpea (532 kg) followed by sesame (283 kg) and Indian jujube (144 kg) in agrihorticulture block. Fodder sorghum produced 2314 kg green fodder which was equivalent to 581 kg BEY. The silvipastoral module recorded 2051 kg green fodder (BEY, 129 kg) from TSH, 2233 kg green fodder (BEY, 180 kg) from *Stylosanthes* and 203 kg *Leucaena* dried leaf meal (BEY, 204 kg). The boundary plantation produced 1600 kg fresh spine-less fodder cactus cladodes (BEY, 115 kg), 110 kg *Leucaena* leaf meal (BEY, 111 kg) and 5 kg *Grewia* fruits. Apart from this, the various food crops in the model produced total 2741 kg dry fodder/year comprising of barley straw (1496 kg), groundnut stover (325 kg), sesame stover (207 kg) and chickpea stover (405 kg from food crop component and 308 kg from agrihorticulture).

Table 3

Yield, barley equivalent yield (BEY) and economics under rain water harvesting and agroforestry based rainfed farming system (mean of 4 years)

Particulars	Component*	Yield (kg/plot)**	BEY (kg/plot)	Cost of production (US\$)***	Gross returns (US\$)	Net returns (US\$)	B:C ratio
Food crops	Groundnut	240 ± 41 (325 ± 55)	718	103	165	62	1.6
	Barley	1021 ± 47 (1496 ± 105)	1021	114	298	184	2.6
	Sorghum	2314 ± 170	581	55	123	68	2.2
	Chickpea	311 ± 30 (405 ± 67)	925	86	218	132	2.5
Agrihorticulture	Indian jujube	200 ± 50	144	22	15	-7	0.7
	Sesame	81 ± 6 (207 ± 33)	283	35	66	32	1.9
	Chickpea	179 ± 29 (308 ± 74)	532	66	178	112	2.7
Silvipasture	TSH grass (GFY)	2051 ± 402	129	13	32	19	2.5
	<i>Leucaena</i> (LM)	203 ± 51	204	12	39	27	3.3
	<i>Stylosanthes</i> (GFY)	2233 ± 126	180	10	39	29	3.9
Boundary plantation	Cactus + <i>Leucaena</i> + <i>Grewia</i>	1600 ± 300	115	6	25	19	4.2
		110 ± 17	111	10	30	20	2.9
		5 ± 1	38	4	16	12	4.1
Farm pond	-	-	-	53	-	-	-
Total (1 ha)	-	-	4979	589	1244	709	2.1
*Where TSH, GFY and LM are tri-species hybrid, green fodder yield and leaf meal, respectively.							
**Figures in the parenthesis are by-product of the crop and the value after ± is SE.							
***The currency mean exchange value: 1 US \$ = 65 Indian Rupee (₹)							

The cost of cultivation, gross returns, net returns and benefit cost ratio of different components and whole rainfed model are described in Table 3. The total cost of cultivation, gross returns, net returns and benefit cost ratio of the one ha rainfed farming system model was 589 US\$, 1244 US\$, 709 US\$ and 2.1, respectively. It is evident from the Fig. 1 that the contribution of food crop component (446 US\$) was the highest (62.9%) in the total net returns of the model and it was followed by agrihorticulture (137 US\$, 19.3%), silvipasture (75 US\$, 10.6%) and boundary plantation (51 US \$, 7.2%).

Goat production potential and profitability

The small ruminant carrying capacity of the studied rainfed farming system model was calculated by dividing the dry matter (DM) availability from the model ($3150 \text{ kg ha}^{-1}\text{year}^{-1}$) by the DM requirement for one growing goat under intensive rearing system ($350 \text{ kg DM goat}^{-1}\text{year}^{-1}$) and semi-intensive rearing system ($90 \text{ kg DM goat}^{-1}\text{year}^{-1}$) (Table 4). The carrying capacity of the above model was found to be 9 and 35 goat year^{-1} under intensive and semi-intensive rearing systems, respectively. The economic potential of the model was estimated under intensive and semi-intensive goat rearing systems (Table 4). Nearly 294 and 459 US\$ initial investment was needed for animal shed, fencing, equipment and electric and water tank installations under intensive and semi-intensive rearing systems, respectively. The cost of animal shed comprised 74% of the total initial investment in both the systems of small ruminant rearing. Yearly fixed cost due to initial investment was found to be 41 and 65 US\$ under intensive and semi-intensive rearing systems, respectively and was calculated by adding the interest on initial investment (@ $7\% \text{ annum}^{-1}$), yearly depreciation and amortization cost (Table 4). The variable cost under intensive and semi-intensive small ruminant rearing system was 1293 and 3026 US\$ year^{-1} , respectively and consisted of animal cost, feed and fodder cost, labour cost, veterinary expenses and other miscellaneous cost. The feed and fodder cost was found to be the major cost (46%) followed by animal cost (30%), labour cost (21%) and others in intensive rearing system while animal cost, labour and feed and fodder constituted 50, 28 and 19% of the total variable cost in semi-intensive rearing system.

Table 4
Goat carrying capacity and economic potential of the rainfed farming system model under
intensive and semi-intensive rearing systems

Particulars	Goat rearing system	
	Intensive	Semi-intensive
Carrying capacity		
DM availability from model (kg ha ⁻¹)	3150	3150
DM required for 1 growing goat (15–38 kg body weight) (kg)	350	90
Carrying capacity of model (goat ha ⁻¹)	9	35
Initial investment (US \$)		
Animal shed	218	341
Fencing	49	58
Equipment	16	40
Electricity and water tank installation	10	21
Total initial investment	294	459
Interest on investment (@ 7%/annum) – A	21	32
Junk value	77	108
Length of useful life (years)	25	25
Yearly depreciation – B	9	14
Amortization cost – C	12	18
Yearly fixed cost due to initial investment (A + B + C) – D	41	65
Variable cost (US \$)		
Animal cost	388	1508
Feed and fodder (from model)	589	589
Labour	267	842
Veterinary care	21	32
Miscellaneous expenses	29	55
Total variable cost – E	1293	3026
Total cost (D + E)	1334	3090
Returns (US \$)		
Meat	1740	3764
Skin	35	135
Manure	75	179
Return from sale of non-edible produce from model	377	352
Gross returns	2226	4430
Net returns	892	1340
B:C ratio	1.7	1.4
Decimal values are rounded to its nearer value; 1 US \$ = 65 Indian Rupee		

The gross return from the intensive rearing system was US\$ 2226 and consisted of returns from meat (US\$ 1740, 78%), skin (US\$ 35, 2%), manure (US\$ 75, 3%) and sale of non-edible produce (US\$ 377, 17%). On the other hand, the semi-intensive rearing system yielded US\$ 4430

gross returns out of which, 85% (US\$ 3764) was from animal meat, 3% (US\$ 135) from skin, 4% (US\$ 179) from manure and 8% (US\$ 352) from sale of non-edible produce from the model. The intensive and semi intensive small ruminant rearing system produced US\$ 892 and 1340 net returns, respectively with the corresponding benefit cost ratio of 1.7 and 1.4 (Table 4). It is evident from the study that inclusions of small ruminants in rainfed farming model both as intensive and semi-intensive systems can enhance the profitability of the farm family. The net return from the rainfed farming system was US\$ 709 which can increase to US\$ 892 and 1340 if small ruminants are included under intensive and semi-intensive systems, respectively. The net returns increased by 26 and 89% on inclusion of goat under intensive and semi-intensive rearing system, respectively in water harvesting and agroforestry based rainfed farming system model.

Resilience

The inclusion of goat, agroforestry (tree) and farm pond for rain water harvesting in the rainfed farming have resulted in higher profitability and resilience to less rainfall and its aberrations (Table 5 and Fig. 2). A survey of rainfed farmers having different components revealed that net returns increased with inclusion of livestock (US\$ 521 ha⁻¹), livestock + tree (US\$ 586 ha⁻¹) and livestock + tree + farm pond (US\$ 857 ha⁻¹) in the production system. The contribution of crop component in crop + livestock, crop + livestock + tree and crop + livestock + tree + farm pond rainfed farming systems in net income was 75, 70 and 80%, respectively while the corresponding contribution of livestock was 25, 18 and 10%. The contribution of tree component was 0 (crop + livestock), 12 (crop + tree + livestock) and 10% (crop + tree + livestock + farm pond) in net return. The farmers reported 24, 20 and 6% chances of crop failure due to aberrant rains in crop + livestock, crop + livestock + tree and crop + livestock + tree + farm pond rainfed farming systems, respectively during the rainy season. During the winter season, 100% chances of crop failure were reported by farmers in crop + livestock and crop + livestock + tree based farming systems. They further observed that the chances of crop failure due to aberrant rainfall during the winter season reduced to 5–10% if farmers had a farm pond for rain water harvesting and recycling. In on-station rainfed farming system model also no crop failure was observed due to provision of farm pond where rain water was harvested and efficiently utilized through sprinkler system for irrigation of crops as and when needed. Further, the resilience in net income was the highest (1340 US\$ ha⁻¹) when goat rearing was included under semi-intensive system followed by intensive system (Fig. 2).

Table 5
Profitability and resilience of various on-farm rainfed farming systems

Rainfed farming system (components)	Farmer's profile						Net return (US\$ ha ⁻¹)	% contribution in net income			Chances of crop failure due to aberrant rain (%)	
	Number	Age (year)	Family size (no.)	Farming experience (years)	Land holding (ha)	Livestock (no.)		Crop	Livestock	Tree	Rainy	Winter
Crop + Livestock	42	48 ± 1.8	9.1 ± 1.1	23 ± 2.1	1.7 ± 0.2	7.2 ± 1.9	521 ± 18	75 ± 2	25 ± 2	0	24 ± 1.4	100
Crop + Tree + Livestock	32	51 ± 1.9	8 ± 1.2	25 ± 1.8	1.9 ± 0.2	5.5 ± 0.7	586 ± 22	70 ± 1.6	18 ± 1.9	12 ± 0.9	20 ± 1.9	100
Farm pond + Crop + Tree + Livestock	11	52 ± 1.9	8.4 ± 2.2	22 ± 2.4	2.1 ± 0.3	7.2 ± 1.1	857 ± 66	80 ± 2.1	10 ± 0.7	10 ± 1.8	6 ± 1.4	5–10
Figures after ± is SE; The currency mean exchange value: 1 US \$ = 65 Indian Rupee (₹)												

Discussion

The results indicated that integration of rainfed crops, perennial components like *Leucaena*, tri-species hybrid grass and *Stylosanthes* (silvipasture), *Ziziphus mauritiana* (agrihorticulture) and small ruminants (goat) in conjunction with rain water harvesting through farm pond in rainfed farming systems offered an opportunity to increase farm productivity, profitability and resilience. Cropping in rainfed agro-ecological situations of central India relies mostly on the annual rainfall distribution, where crops are mainly grown during the rainy season with 100% cropping intensity. For taking second crop, approaches like rain water harvesting in farm ponds and using it for life saving irrigations especially under rainfed situation has been found extremely useful. In Bundelkhand region of central India, the rugged and undulating topography and hard underground strata offer great opportunities for rain water harvesting in farm ponds and reservoirs and recycling it for crop production (Palsaniya et al. 2011; Palsaniya et al. 2012b). In the present investigation, a farm pond of 25 m x 20 m x 2.5 m dimension was dug which resulted in creation of approximately 1.25 x 10⁶ litres of rainwater harvesting and storage facility. This harvested rainwater was used for growing different crops with low water requirements and irrigation was given through a sprinkler system during subsequent dry winter seasons. It is worth mentioning that no winter cropping is possible in the central part of India without rain water harvesting as evident from the on-farm

situation (Table 5). The minimum water requirement in terms of MAI of Chickpea was calculated as a case during different years is presented in Fig. 3. To satisfy this MAI limit, deficit irrigation has been provided from the water harvested in the pond. Water balance showed that in the first fortnight of October, the MAI index is below 0.30 during all the four season except in 2015-16, therefore without pre irrigation sowing of this crop was not possible. Whenever MAI values become less than 50% of available water content, irrigation was applied from farm pond. However, in the farmer's field crop was failed due to lack of water resource. It can be seen that to satisfy the requirement of MAI during different growth stages, one to two irrigation along with pre-sowing irrigation helped to grow chickpea under rainfed condition. To satisfy the moisture availability index of crop, one irrigation (40 mm) was applied for sowing and one irrigation during vegetative stage of crop fulfilled the water requirement and further 5 rain storms during reproductive stage resulted in good production of chickpea crop during winter season of 2014-15. However, during 2015-16, two rain storms facilitated to sow the crops and only two irrigations were applied during vegetative and reproductive phases satisfied the MAI limit. In the 2016-17 and 2017–2018, crop was raised by applying irrigation since no rainfall occurred and consecutive stages were provided two irrigations for successful crop growth and yield. Provisioning of water through water harvesting for irrigation in the rainfed farming system created opportunity for double cropping and thereby increasing the cropping intensity to 200%. Farmers without any irrigation source confirmed 100% chances of crop failure during winter season in absence of rain water harvesting. Thus rain water harvesting imparted resilience in the rainfed farming systems and made the double cropping a reality. Ray et al. (2020) also reported enhanced cropping intensity to 168% in rainfed areas of north eastern India through rain water harvesting facilities. Anantha et al. (2021) concluded that integration of *in-situ* and *ex-situ water harvesting* practices hold promise to bridge the yield gap while ensuring sustainable intensification and livelihood resilience in the south Asian smallholder farming systems.

Inclusion of perennial components (trees and grasses) not only enhances productivity but also provides livelihood resilience to rain fed farmers as these components are less affected by the vagaries of weather (Dhyani et al. 2011). The *Leucaena*, tri-species hybrid grass and *Stylosanthes* produced much needed fodder for livestock and *Ziziphus mauritiana* produced fruits for human consumption without any external application of water in the present farming system model. The annual crops are well known to have vulnerability to drought compared to perennial crops. Dev et al. (2020) while working at the same location also concluded that inclusion of perennials as agroforestry helped in increasing productivity, profitability and livelihood security in rainfed semi arid tropics. Farmers consider drought resistance and livelihood resilience as the main motivating factors while adopting agroforestry in this part of India (Palsaniya et al. 2010).

Inclusion of goat in vulnerable rainfed farming system offered great opportunities for enhancing profitability and resilience. Higher and favourable crop-livestock interactions, less market dependency and greater flexibilities have also been reported in less vulnerable mixed crop-livestock systems by Sneessensa et al. (2019). The total return in goat rearing increased with the flock size from intensive to semi intensive system and corroborated with earlier findings of Dixit and Singh (2014) and Tanwar and Chand (2013). However, net return per goat was higher in intensive system with smaller flock size than semi intensive system and resembles with earlier reports of Kumar et al. (2014) and Shivakumara and Siddaraju (2019). This indicated that intensive rearing system involves high cost of production but it is compensated by higher productivity of animals. The present result suggests that combining grazing with supplementation is potentially more profitable than pen-feeding with no grazing and corroborated with the findings of Legesse et al. (2005). Thus, goat rearing under integrated system may provide opportunities of regular income and can generate more employment to the farming family around the year. The higher net income due to the inclusion of goat highlighted the importance of animals in enhancing the livelihood of rainfed livestock keepers. Ray et al. (2020) reported 56.6% more net return due to inclusion of livestock in the farming system. Singh et al. (2010) also observed higher net income from livestock component in the semi-arid areas of Bundelkhand region in India. Higher returns and more secured livelihood of the semi-arid Bundelkhand farmers through crop-livestock based interventions were also reported by Dwivedi et al. (2018). The multiple and diverse components in farming system (crop, tree, livestock, etc) also ensure that a farmer gets assured regular income and employment.

The enhanced and assured productivity and profitability of the farming system model might be due to the positive interactions and synergies among its components. The proper resource recycling among various components under farming system resulted in higher productivity and income. The components in a farming system interact synergistically and the by-product or output of one component is used as input in another which minimizes the external dependence and leads to higher productivity, income and resilience (Palsaniya et al. 2017). Panwar et al. (2018) reported that the perennial components and livestock provide risk proofing to the farmer as they are more stable and less prone to aberrant weather conditions than annual food crops. A large number of other workers also concluded that greater synergies, positive interactions and proper resource recycling among the components of farming systems were largely responsible for enhanced productivity, income and resilience (Kumar et al. 2018; Accatinoa et al. 2019; Palsaniya et al. 2022).

Conclusion

It can be concluded from the present study that intervention of water harvesting, agroforestry and goats in the rainfed farming systems could enhance farm productivity and profitability and impart resilience to the livelihood of farmers. Rain water harvesting is the key for reducing chances of crop failures due to droughts, ensuring double cropping (cropping intensity up to 200%) and sustainable intensification in rainfed areas. The net returns can be further increased by 26 and 89% on inclusion of goat as intensive and semi-intensive rearing system in water

harvesting and agroforestry based rainfed farming system model. The inclusion of perennial components like grasses, trees, etc in the system enhances the resilience and income. Therefore, large scale adoption of rain water harvesting, agroforestry and goat based technology by the farmers is needed to bring phenomenal changes in livelihood of rainfed small holder farming systems.

Declarations

Acknowledgements

The authors sincerely acknowledge the Indian Council of Agriculture Research, New Delhi for funding under the institute EFC and to the Director, ICAR-Indian Grassland and Fodder Research Institute, Jhansi, India for providing all facilities.

Funding

This study received no external funding and necessary funds were allocated under the institute EFC.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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Figures

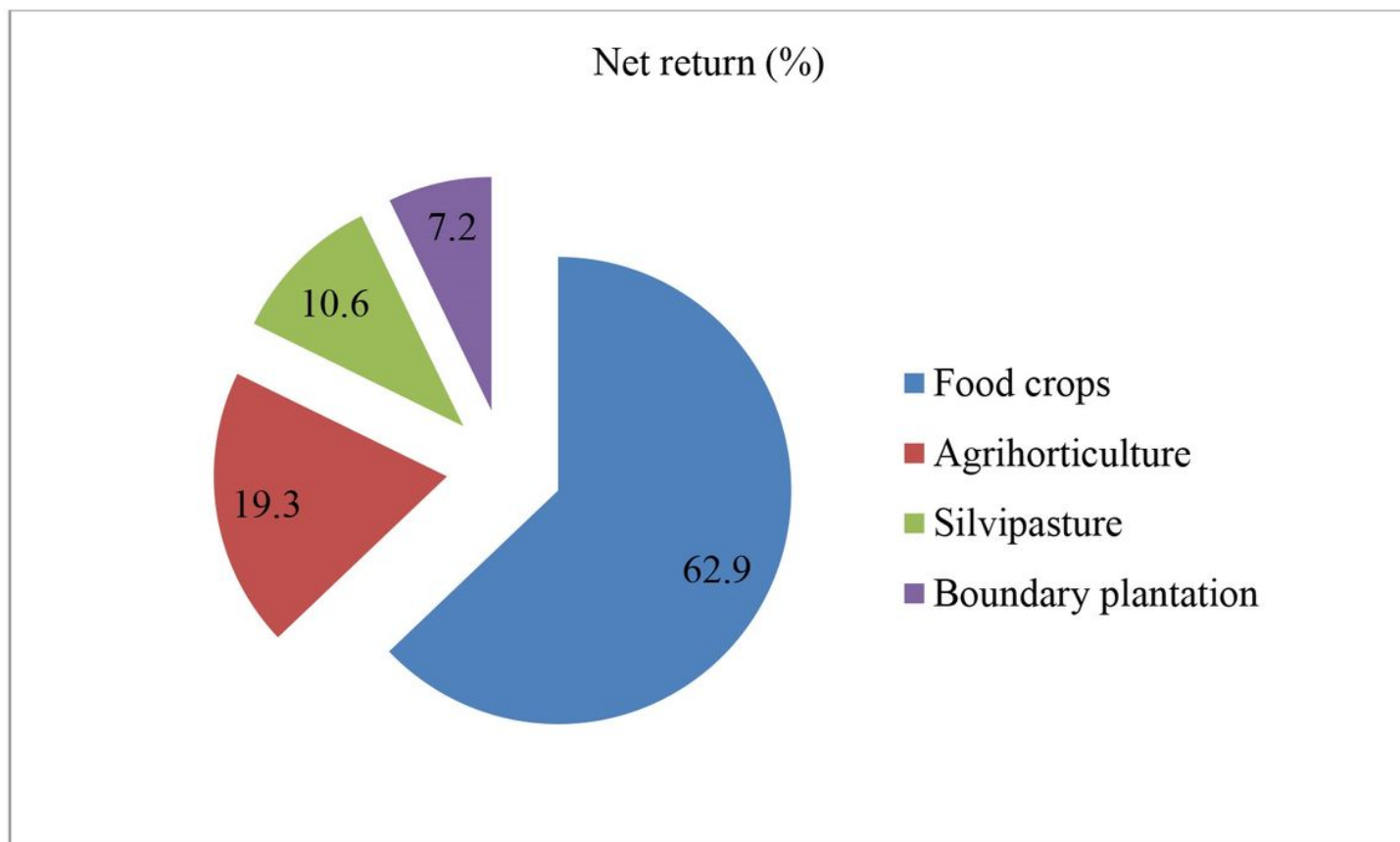


Figure 1

Contribution of various components of farming system to net returns

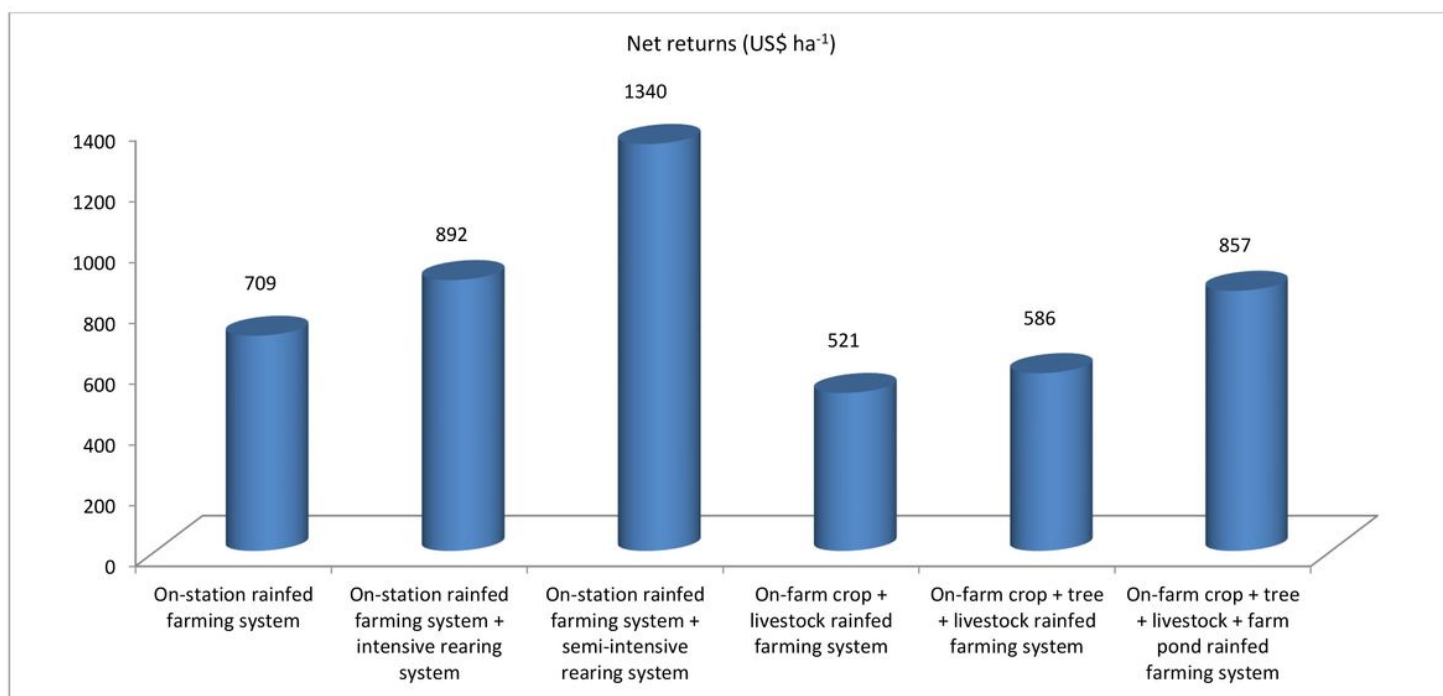
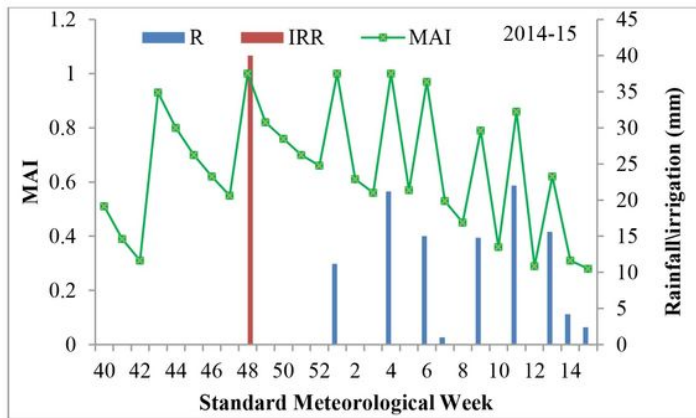
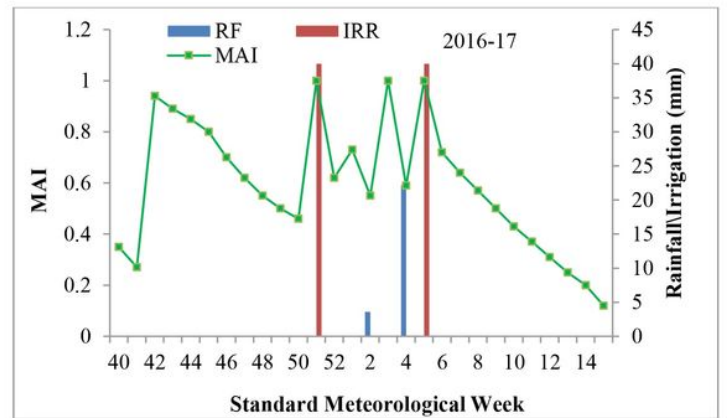


Figure 2

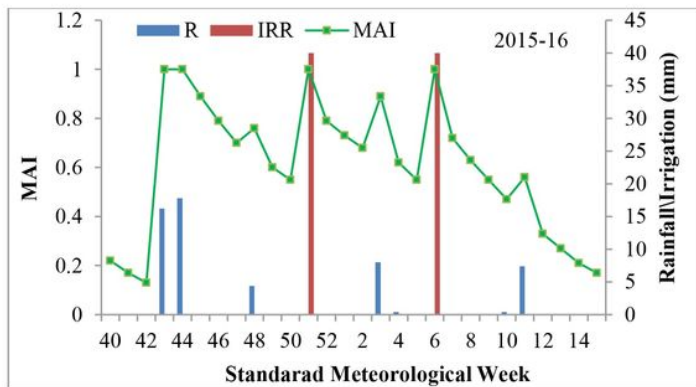
Resilience in profitability under various on-station and on-farm rainfed farming systems



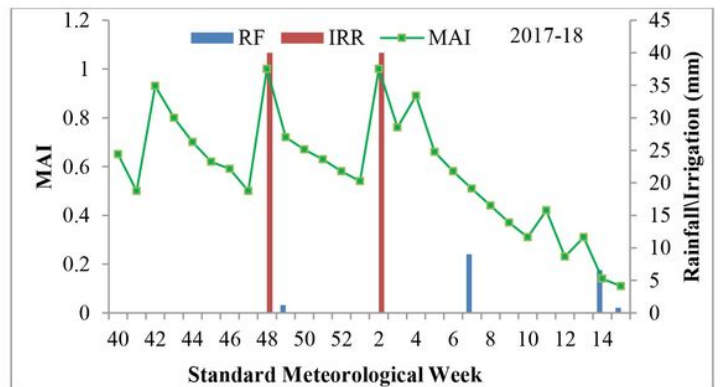
(a)



(c)



(b)



(d)

Figure 3

Rainfall (R), irrigation (IRR) and moisture adequacy index (MAI) during the crop growth period of chickpea in various years (a to d)