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Effect of Compartment Bunding Systems to Enhance the Productivity and Profitability Using Partial Mechanization for Chickpea under Semi Arid Region of Northern Karnataka

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A B S T R A C T

Improving the socio-economic status of the farmers and sustainable food grain production is an important issue in semi-arid regions. Shrinking natural resources due to land degradation, urbanization, climate change, scanty and uneven distribution of rainfall lead to a reduction in the productivity of dryland crops. Hence, the study was conducted on the effect of different sizes of compartment bund system (in-situ moisture conservation) with partial mechanized methods for increasing productivity and profitability of chickpea crop under vertisols of the semi-arid region of northern Karnataka. Chickpea was grown in the rabi season under a compartment bund system of different sizes (in-situ moisture conservation)of 2x2 m and 3x3 m were found best practices for efficient management of in-situ moisture content in vertisols which significantly increases the grain yield, water use efficiency, and water productivity. In addition to this, the compartment bund system with partial mechanization in various operations i.e., from land preparation to harvesting and threshing increases the farm income, in terms of gross return, the net return, and B: C ratio by reducing input cost. About 30 to 60 percent of chickpea yield was achieved by adopting compartment bunds with partial mechanical methods in rainfed regions.

Introduction

From a global perspective, water conservation is playing a key role in increasing water productivity of dryland crops especially in rainfed areas of the Semi-Arid Tropical (SAT) region. From a regional point of view, unpredicted or erratic distribution of rainfall, reduction of rainy days, increasing the intense rainfall pattern results in a higher runoff, soil erosion, moreover shift in sowing and harvesting periods will lead to a reduction in yield of the crops grown during rabi season. About 73 percent of the area is available for cultivation of crops in the world and in India, about 60 percent of the area is available for cultivation of crops under rainfed condition, which contributes to 40 percent of the total food production. In India, crops like sorghum (93%), pearl millet (94%), maize (79%), pulses (87%), oilseeds (76%) and cotton (64%) were grown under dryland conditions and these crops will act as a source of fodder for a major livestock production system (Singh *et al.,* 2007; Somasundaram *et al.,* 2014). After the implementation of the World Trade Organization (WTO) and Intellectual Property Rights (IPR) on account of globalization of agriculture, pulse crops play a key role in nutritional security by meeting protein requirements for diet. Enhancement of productivity of cropping systems through natural resources with a crop rotation with pulses increases the fertility of soils and yields in cereals and oilseeds (Tripathi, 2010; Gan *et al.,* 2002). Besides, the cultivation of pulse crops increases the profitability through higher net returns and also additional profit due to lower cost of production (Curforth *et al.,* 2013; Gowda *et al*., 2013). Production of field crops that are rich in proteins is very important for nutritional security (Gowda *et al.,* 2013). India is the largest pulse producing country in the world which nearly produces 25% of the world's share (IIPR, 2011). In India, production of pulse crops was about 17.21million tonnes from an area of 24.78 million hectares (Nadarajan, 2013) and expected to produce 32 million tonnes by 2030 to meet projected demand (Anonymous, 2011). Chickpea was the major pulse crop cultivated during the winter season in the Vertisols of south India. With the growing population, per capita availability of soil and water resources are shrinking day by day, and thereby increasing scarcity of crop production in the country highlights the importance of optimizing its use. Inadequate availability of water resources for agriculture due to erratic rains and high evapotranspiration affects the increasing demand for water for agriculture, domestic and industrial use. The issues concerning land degradation and loss of soil fertility due to land-use intensification and climate change the availability of water and agricultural land is increasingly becoming a scarce resource for food production, the need for innovation in land-use efficiency and to enhance crop productivity from water resources. Moreover, efficient utilization of rainwater is of great concern for the improvement and sustainability of agriculture in the dryland agroecosystem. Besides, the presence of black soils with high clay content and low infiltration rate results in 10 to 30% runoff with loss of fertile top-soil. In such conditions, *in-situ* rainwater conservation techniques can enhance the crop yields especially in drought conditions (Patil and Sheelavantar, 2004; Rao *et al*, 2007; Venkateswarlu and Shanker, 2009). With the aim of harvest every drop of rainwater in situ and increase the water use efficiency for higher crop productivity. Hence in rainfed areas, the *in-situ* rainwater harvesting in the form of the compartmental bunding system has tremendous scope for increasing the productivity of the rainfed area. Compartmental bunding was used to conserve the rainwater in situ, recharge soil profile uniformly reduces runoff, soil and nutrient losses, and increases crop yields on a sustainable basis, but due to intensive labour requirement compartment bunding system was limited scope for its adoption by the growers. Also, high energy investment in terms of mechanical energy for the formation of compartment bunds and require more investment in the hiring of bullock pairs and farm labours. Moreover, due to labour scarcity and increasing the labour cost, farmers are facing acute problems for their agricultural production. Therefore, there is a need for alternate technologies to address the aforementioned issues, especially in field crops. Mechanization for the cultivation of field crops is an alternative to increase the farm income by reducing input cost and drudgery on labour.

In this context, a study was conducted for two years (2017-19) at Regional Agricultural Research Station, Vijayapura, Karnataka, India to know the performance of partially mechanization along with different sizes of compartment bunds as in-situ moisture conservation on chickpea yield, water productivity and economic befits comparison with the traditional methods of cultivation.

Materials and Methods

Study area: A three year (2017-2019) field experiment was done to study the effect of various sizes of compartment bunds constructed by using tractor-drawn and bullock drawn implements on water productivity under chickpea cultivation at Dryland Agricultural Research Centre, Regional Agricultural Research Station (RARS), Vijayapura (Fig. 1). The experimental site was located at Karnataka (India) 16^0 49' North latitude and $75^0$43' East longitude at an altitude of 593.6 m above mean sea level. Vijayapura district is situated in agro-climatic zone-3 of the northern part of Karnataka. Under zone-3, the majority of the farming system situated in a rainfed condition with arid to semi-arid climate. The average rainfall was about 594.40 mm with an average of 30 rainy days in a year.

The normal maximum and minimum temperatures were experienced in the region about 32.8^0C and 20.8 ^{0}C respectively with 71.8 % relative humidity during the morning and 44 % relative humidity in the afternoon onwards. The soil is a medium black clay (16.2% coarse sand, 6.3 % fine sand, 13.2% silt, and 54.3% clay) type. The depth of productive soil ranges from 45 to 60 cm having a bulk density of 1.43 g.cm^{-1} and maximum water holding capacity of 17.6%. The infiltration capacity of the soil is moderate (0.8 to 1.0 cm hr-1) and pH is about 8.5.

Chickpea (JG-11) has been grown during Rabi season (October to January) in the year (2017-2019) under different sizes of compartment bund system. In this experiment, the main treatments are M_1-Partial mechanized method of cultivation and M_2-Traditional method of and sub-treatment are T_1- 6x6m size compartment bunds, T_2- 3x3m size compartment bunds,T_1- 4.5x4.5m size compartment bunds,T_1- 2x2m size compartment bunds, T_5- No compartment bunds (control) with three replications.

Farm operations such as plouging, sowing, inter cultivation, insects and pest control, harvesting, and threshing were performed using the partially mechanized and traditional methods. The formation of different sizes of compartment bunds for in-situ rainwater harvesting was done by using tractor and bullock drawn bund former was shown in Fig. 2 and 3. In the case of a tractor-drawn compartment bund former, the treatment M_1T_4 was done by using double bottom bund formers, and other sizes are done by using a single bottom bund former. Time was recorded for each operation to estimate the field capacity (*ha hr*$^{-1}$.) for all the treatments. Tools and implements are used in various farm operations were listed in table no. 1 for both mechanized and traditional farming methods. Spacing was used and for the other compartment bund system, a single bottom bund former was used (Fig. 4 and 5).

An operation-wise input energy source for cultivation of chickpea was estimated by multiplying energy coefficients with the number of inputs used such as farm labours, farm machinery, seeds, fertilizers, pesticides, and chemicals, etc., as shown in table-1.The estimation of input energy was calculated in terms of direct, indirect, renewable, and non-renewable sources energies (Alam *et al.*, 2005). The input materials such as seeds, fertilizers, manure, chemicals, machinery were used as indirect sources of energy. Whereas, human labours, and fuel (petrol or diesel) were used as a direct energy source. The sources such as fuels, chemicals, fertilizers, and farm machinery were categorized as non-renewable energy sources. Whereas the input sources like human labour, seeds, and manures were categorized as input renewable energy sources. The energy efficiency in various treatments was evaluated by the energy ratio between output and input energy used in the cultivation of chickpea. The input and output energy was estimated by the coefficient of energy equivalent for human labour, farm machinery, fuel, fertilizers, pesticides, herbicides, fungicides, input seeds, and yield values of chickpea.

The different energy indices such as energy use efficiency (EUE), energy productivity (EP), specific energy (SE), and net energy were estimated using the following methods.

$$\text{Energy ratio or energy use effficiency} = \frac{\text{Total energy output } (\text{MJ ha}^{-1})}{\text{Total energy input } (\text{MJ ha}^{-1})} \quad (1)$$

$$\text{Energyproductivity}(\text{kgMJ}^{-1}) = \frac{\text{Grainyield } (\text{kg ha}^{-1})}{\text{TotalEnergyinput } (\text{kg ha}^{-1})} \quad (2)$$

$$\text{Specific energy } (\text{MJ kg}^{-1}) = \frac{\text{Total Energy input } (\text{kg ha}^{-1})}{\text{Grain yield } (\text{kg ha}^{-1})} \quad (3)$$

$$\text{Net energy } (\text{MJ ha}^{-1}) = \text{Totalenergyoutput}(\text{MJha}^{-1}) - \text{Totalenergyinput}(\text{MJha}^{-1}) \quad (4)$$

The Meteorological data was collected from All India Coordinated Research Project on Agro-Meteorology Station (ACRPAM), Regional Agricultural Research Station, Vijayapura. The rainfall and evapotranspiration occur from 2017 to 2019 were presented in figure 6. The soil samples were collected to study moisture distribution patterns in various sizes of the compartment bund system in which soil moisture content was determined by using the gravimetric method (Reynolds, 1970). Rainwater use efficiency was estimated for various sizes of compartment bund systems which can be expressed as the economic yield divided by the seasonal crop water use i.e., seasonal evapotranspiration (Zwarat *et al.,* 2004; Geerts *et al.*, 2009), while the rainwater productivity was estimated which is expressed as the gross return from economic yield divided by the seasonal crop water use i.e. seasonal evapotranspiration(Turner *et al.*, 2004).

$$\text{Rainwater use efficiency}(kg\ ha^{-1}mm^{-1}) = \frac{\text{Economic yield } (kgha^{-1})}{\text{Seasonal evapotranspiration } (mm)} \quad (5)$$

$$\text{Water productivity } (Rs\ ha^{-1}mm^{-1}) = \frac{\text{Gross Return from economic yield } (Rs\ ha^{-1})}{\text{Seasonal evapotranspiration } (mm)} \quad (6)$$

The effect of compartment bund system on in-situ water conservation was assessed through the efficiency of moisture conservation method using the following relation (Kannan *et al.*, 2010)

$$E = \frac{M_2 . 100}{(M_1 + R) \text{ or } S_c \text{ whichever is less}} \quad (7)$$

Where, E = efficiency of moisture conservation (%), M_1 = moisture at the beginning of the crop period (*mm*), M_2 = moisture content at the end of crop period (*mm*), R = rainfall received during crop period (*mm*) and S_c = storage capacity of the soil (*mm*).

Comparison of effects of various sizes of compartment bunds (in-situ water conservation) for chickpea cultivation - an economical analysis was used by using economic tools such as cost of cultivation, net return and Benefit-Cost Ratio (B:C ratio) (Demircan *et al.*, 2006; Ozkan *et al.*, 2004). Split plot design technique was used to analyze the effect of different sizes of compartment bund systems of tractor and bullock drawn implements on the economic yield of chickpea.

Results and Discussion

The energy input for the production of Chickpea

The energy requirement for the formation of the compartment bund was found 894.28 *MJ* ha^{-1} i.e. 7.30 % of total input energy of 12244.56 *MJ* ha^{-1}, which was observed in bund size of2x2 m (M_1T_4) of the compartment bunds formed by the tractor-drawn implement. Whereas, 43.24 MJ of 0.72 % of total input energy was 6800.84 *MJ* ha^{-1} in case of treatment 4.5x4.5 m (M_2T_3) size of compartment bund formed by using bullock drawn implement. Moreover, the highest input energy was 13625.01 *MJ* $ha^{-1}$and the lowest was 7948.31 *MJ* ha^{-1}were observed in M_1T_2 and M_1T_5 treatments respectively. Whereas 6800.84 *MJ* $ha^{-1}$and 5973.84 *MJ* $ha^{-1}$of the highest and lowest input energy were observed in M_2T_4 and M_2T_3 respectively.

Highest and lowest input energy required for the cultivation of chickpea under various treatment were found highly fluctuated due to inter cultivation and weed management operations. Operation-wise and sources-wise summary of energy input used in the cultivation of chickpea under mechanized and traditional methods were presented in Table. 3, 4, 5, and 6.

The input energy in the form of direct energy was observed highest in M_1T_2 treatment (5766.93*MJ* ha^{-1}) while lowest in M_2T_3 (1196.45 *MJ* ha^{-1}) treatment and indirect energy was observed highest in M_1T_2 treatment and lowest in M_2T_3 treatment i.e. 7858.08 *MJ* $ha^{-1}$and 4777.40 *MJ* ha^{-1}respectively. In the form of renewable energy highest input was observed in M_2T_4 (1646.44 *MJ* ha^{-1}) and the lowest was M_1T_1 (1072.72 *MJ* ha^{-1}). Moreover, the highest and lowest input energy was observed in M_1T_2 (13625.01 *MJ* ha^{-1}) and M_2T_3 (5973.84 *MJ* ha^{-1}) respectively in the form of non-renewable energy source. The summary of input sources of direct, indirect, renewable, and non-renewable energies for various sizes of compartment bund systems are presented in Table. 5.

The source-wise input quantity and its energy use such as human, fuel, farm machinery, tractor, bullock pair, fertilizers, insecticides, pesticides, and seed for various sizes of compartment bund systems were presented in table no.5 and 6. The input source such as human labour, farm machinery with tractor or bullock drawn implement, and chemicals required quantity were found highly fluctuated for inter cultivation, weed management, insects, and pest management. This is due to the natural condition of weed growth in the field, insects, and pest attach due to variation in the weather condition during growth stages of chickpea cultivation. The percent wise various sources wise input energy was presented in figure 7.

Input energy was recorded to perform sowing and inner cultivation operations, while the lowest input energy requirement was recorded for threshing operation. The operation wise input energy requirements for various field operations were presented in table no. 4 and 5.

Particularly the input energy requirement for the formation of compartment bund under the partial mechanized system was recorded, 894.28 *MJ* ha^{-1} which was highest in M_1T_4 and 156.63 *MJ* $ha^{-1}$was recorded lowest in M_1T_1 treatment. Whereas in the traditional system, 205.75 *MJ* $ha^{-1}$was recorded highest in M_2T_4, and lowest in M_2T_1 was 33.93 *MJ* ha^{-1}. Operation-wise various input energy sources were presented in figure 8.

Performance of partial mechanization and compartment bunding

Performance of various farming systems under the compartment bund system was assessed through various factors, such as field capacity of tractor and bullock drawn farm implements, energy indices (Table no. 2 and 3), economical indicators, yield, water productivity and efficiency of moisture conservation methods. The effect of various sizes of compartment bunds on yield, economics, water use efficiency, water productivity, and efficiency of moisture conservation was presented in table no 8 and 9.

Field capacity

Different types of implements are used for various farm operations in partial mechanized and traditional cultivation methods for the preparation of different size of compartment bunds along with the field capacities were presented in table no. 8. It was observed that there is no significant difference in the input energy required for various sizes of compartment bunds for various operations. The highest field capacity was observed in partially mechanized system M_1T_1 (1.68 *ha.hr*$^{-1}$) and lowest in M_1T_4 (0.29 *ha.hr*$^{-1}$) for the formation of compartment bunds in the field. Whereas, highest field capacity was observed for the formation of compartment bunds in M_2T_1 (0.43 *ha.hr*$^{-1}$) treatment and in case of the traditional method of cultivation the lowest field capacity was observed in M_2T_4 (0.10 *ha.hr*$^{-1}$) treatment.

Hence, the aforementioned results indicated that the field capacity of various operations can be increased by replacing manual methods with partial or full mechanization. Hence, Fully mechanized field operations increase input energies, and thereby, it increases the field capacity of various operations and without mechanized field, operations mean fewer input energies, and thereby, it reduces the field capacity of various operations.

Energy productivity

Energy productivity of partial mechanized and the traditional based different size of compartment bunds was evaluated. The results revealed that under a partial mechanized system higher energy efficiency of 5.20 was recorded with higher energy productivity (0.15 *kg MJ*$^{-1}$) and specific energy (6.48 *MJ kg*$^{-1}$) in M_1T_2. Whereas, lower energy efficiency was recorded 2.18 with lower energy productivity (0.06 kg *MJ*$^{-1}$) and specific energy (15.73 *MJ kg*$^{-1}$) under the partial mechanized system (M_1T_3) without compartment bunds. Meanwhile, under the traditional system of cultivation, a higher energy efficiency (3.80) was recorded with energy productivity and specific energy of 0.11 *kgMJ*$^{-1}$ and 8.93 *MJ kg*$^{-1}$ respectively, in M_2T_3. Lower energy efficiency was observed under the traditional system of cultivation in M_2T_4 without compartment bunds i.e energy efficiency (2.07), energy productivity (0.06 *kg MJ*$^{-1}$), and specific energy (16.38 *MJ kg*$^{-1}$).The net energy in the partial mechanized system for the treatment $M_1T_4$was recorded highest 26826.28*MJ ha*$^{-1}$and followed by $M_2T_2$was 25800.84*MJ ha*$^{-1}$ respectively. The lower net energy was found in M_1T_5 and M_2T_4 i.e. 16673.88*MJ ha*$^{-1}$ and 11423.56*MJ ha*$^{-1}$ respectively in the partial and traditional mechanized system.

These results indicated that the higher energy input usage increases the field capacity of particular field operations, thereby reduces the time required to complete the particular field operation. In addition to this, a partial mechanized system along with moisture conservation method will help to increase crop productivity (yield) and other benefits such as water use efficiency, water productivity, and net income.

Effect of in-situ moisture conservation through compartment bunds

In this experiment, the compartment bund system was adopted as an in-situ moisture conservation technique. Statistical analysis indicated that in a compartment system M_1T_4 treatment was found a sign with the highest yield of 1341.02 $kg\ ha^{-1}$ and water use efficiency of 7.08 $kg\ ha^{-1}\ mm^{-1}$, water productivity of Rs. 264 $ha^{-1}\ mm^{-1}$. Hence, M_1T_4 was significantly highest as compared to other treatments. Moisture conservation efficiency was also highest in M1T4 (64.84 %) followed by M2T2 (63.38 %) and M2T4 (62.58 %). There was an insignificant difference in partial mechanized and traditional systems of cultivation in terms of water use efficiency, water productivity, and efficiency of moisture conservation methods. But due to in-situ moisture conservation such as the formation of compartment bund of different sizes revealed that, as the bund size reduces and thereby it increases the crop yield, water use efficiency, water productivity and efficiency of moisture conservation method. In both, the system of cultivation i.e. partial mechanized and traditional cultivation method: the compartment bund size of 2x2 m and 3x3 m were recorded higher yield, higher water use efficiency, higher water productivity, and higher efficiency of conservation method. The results revealed that average yield was increased to 61% in 2x2 m size of compartment bunds and 30 % in 3x3 m size of compartment bunds as compared to the average yield of control (Without compartment bunds). Similarly, this result was supported by the study of the Bundelkhand region of Northern Indian states revealed a higher chickpea yield when the crop was sown during the winter season in higher moisture content (Narain *et al.,* 2014). Also, the chickpea yield was improved in a different land configuration such as furrow raised beds of 60 cm width was effective in conserving soil moisture to enhance the crop productivity (Mishra *et al.,* 2012). In addition to this, Chickpea yield was found 43.90% higher in the compartment bund size of 10 x 10 m under vertisols of the Bellari region of Southern India as compared to farmers' practice (Patil *et al.,* 2016).

Table.1 Tools and implements used in the farm operations

Sl. No	Particulars of field operations	Partial mechanized system		Traditional system	
		Type of implement	Power source	Type of implement	Power source
1.	Ploughing	MB plough	Tractor	MB plough	Tractor
2.	Compartment bunding	Bund former *	Tractor	Bund former	Bullock pairs
3.	Harrowing	Blade harrow	Tractor	Blade harrow	Bullock pairs
4.	Sowing	Seed cum fertilizer drill	Tractor	Seed cum fertilizers drill	Bullock pairs
5.	Intercultivation.				
	1^{st}weeding	portable power cultivator	Small petrol engine	Animal drawn Hoe	Bullock pairs
	2^{nd}weeding	power tiller operated sweep cultivator	Power tiller	WHEEL HOE (cycle weeder)	Manual

	3rd weeding	WHEEL HOE (cycle weeder)	Manual	Animal drawn Hoe	
6.	Insects and pest management				
	1st spraying	tractor mounted sprayer	Tractor	Napsack sprayer	Manual
	2nd chemical spraying	tractor mounted sprayer	Tractor	Napsack sprayer	Manual
7.	Harvesting	Sickel (one person)	Manual	sickel (one person)	Manual
8.	Threshing operation	Spike tooth thresher	3-7.5 hp Diesel Engine	Spike tooth thresher	3-7.5 hp Diesel Engine

***** Formation of 2x2 m size compartment bunds a double bottom bund former with 2-meter

Table.2 The energy equivalent of input and output used in the production of Chickpea

Particulars	**Units**	**Energy equivalent (MJ)**	**References**
Inputs :			
1. Mechanical energy			
Human labour	hours	1.96	Erdal*et al*., 2007; Yousefi and Damghani, 2012
Bullock pair	hours	10.1	Chilur and Yadachi, 2017
Machines	hours	62.7	Erdal*et al*., 2007; Esengun*et al*., 2007
2. Chemical Energy			
i. Organic and inorganic Fertilizers			
Nitrogen	kg	60.60	Chilur and Yadachi, 2017
Phosphorous	kg	11.10	Chilur and Yadachi, 2017
Potassium	Kg	6.70	Chilur and Yadachi, 2017
FYM	kg	0.30	Chilur and Yadachi, 2017
i. Plant protections			
Chemicals	kg	120	Ozkan*et al*., 2007; Demircan*et al*., 2006
Water	L	0.63	Erdal*et al*., 2007; Esengun*et al*., 2007
3. Bio-energy			
Seeds	kg	14.70	Kitani, 1999; Salami *et al*., 2014
Outputs:			
1. Grain yield	kg	17.70	Kitani, 1999 ; Salami *et al*., 2014
2. Stover yield	Kg	12.50	Shilpha*et al*., 2018

Table.3 Operation wise energy inputs used in the cultivation of chickpea using partial mechanized method

Sl. No	Particulars	M_1T_1		M_1T_2		M_1T_3		M_1T_4		M_1T_5	
		Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)
1	Ploughing	776.67	8.26	747.99	5.49	704.13	7.20	892.18	7.29	553.58	6.96
2	Formation of compartmenet bunds	156.63	1.67	884.23	6.49	262.61	2.69	894.28	7.30	--	--
3	Land preparation for sowing	662.38	7.04	184.60	1.35	444.59	4.55	790.80	6.46	397.75	5.00
4	Sowing	3944.60	41.94	3817.47	28.02	3676.88	37.62	3973.50	32.45	4143.02	52.12
5	Intercultivation and weed management	3285.38	34.93	7168.75	52.61	4245.14	43.44	5095.98	41.62	2290.29	28.81
6	Insects & pest control measures	351.12	3.73	596.97	4.38	212.37	2.17	321.46	2.63	231.88	2.92
7	Harvesting	137.53	1.46	141.58	1.04	142.99	1.46	141.87	1.16	129.03	1.62
8	Thresing	90.31	0.96	83.42	0.61	84.70	0.87	134.49	1.10	202.76	2.55

Table.4 Operation wise energy inputs used in the cultivation of chickpea using a traditional method

Sl. No	Particulars	M_2T_1		M_2T_2		M_2T_3		M_2T_4		M_2T_5	
		Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)	Energy (MJ)	Energy (%)
1	Ploughing	794.85	12.95	886.78	13.78	749.80	12.55	997.62	14.67	720.24	11.04
2	Formation of compartmenet bunds	33.93	0.55	109.79	1.71	43.24	0.72	205.75	3.03		0.00
3	Land preparation for sowing	192.02	3.13	210.58	3.27	166.99	2.80	183.29	2.70	209.48	3.21
4	Sowing	2893.56	47.13	2853.68	44.33	2976.23	49.82	3137.60	46.14	3391.97	51.97
5	Intercultivation and weed management	1019.23	16.60	1093.77	16.99	905.79	15.16	974.11	14.32	923.18	14.15
6	Insects & pest control measures	978.67	15.94	1028.25	15.97	915.84	15.33	1052.36	15.47	1078.92	16.53
7	Harvesting	136.93	2.23	150.77	2.34	138.38	2.32	143.41	2.11	131.07	2.01
8	Thresing	90.31	1.47	103.46	1.61	77.59	1.30	106.69	1.57	71.60	1.10

Table.5 Energy sources utilizing direct, indirect, renewable, and non-renewable energies in used cultivation of Chickpea

Sl. No	Particulars	Energy, MJ/ha									
		M_1T_1	M_2T_1	M_1T_2	M_2T_2	M_1T_3	M_2T_3	M_1T_4	M_2T_4	M_1T_5	M_1T_5
1	Direct energy	3231.38	1268.76	5766.93	1429.11	3042.46	1196.45	4514.81	1525.11	3024.72	1183.63
2	Indirect energy	6173.24	4870.75	7858.08	5007.97	6730.95	4777.40	7729.75	5275.72	4923.59	5342.82
3	Renewable energy	1072.72	1492.62	1101.01	1562.00	1150.48	1477.40	1274.64	1646.44	1194.54	1432.06
4	Non-renewable energy	8331.90	4646.88	12524.00	4875.08	8622.93	4496.44	10969.93	5154.40	6753.77	5094.38

Table.6 Sources wise energy inputs used in the cultivation of chickpea using partial mechanized method

Sl. No	Particulars	M_1T_1		M_1T_2		M_1T_3		M_1T_4		M_1T_5	
		Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)
1	Human Labours (Hours)	157.31	308.32	196.74	385.61	176.98	346.88	222.82	436.74	161.96	317.44
2	Fuel (Lites)	51.91	2923.06	95.57	5381.12	47.87	2695.58	72.42	4078.08	53.91	2707.28
3	Farm Machinery and Tractors (Hours)	78.26	2875.91	108.40	4590.54	96.95	3763.39	107.99	4640.95	96.13	1420.44
4	Chemical Fertilizers (Kg)	15.24	2477.26	11.39	2493.76	12.81	2104.26	7.75	2182.58	10.40	2550.43
5	Insecticides (Kg)	0.28	56.38	0.29	58.37	0.30	59.70	0.34	68.32	0.38	75.62
6	Seed (Kg)	52.00	764.40	48.67	715.40	54.67	803.60	57.00	837.90	59.67	877.10
Total Input Energy (MJ)		**9404.62**		**13625.01**		**9773.41**		**12244.56**		**7948.31**	
Grain Yield Kg ha^{-1}		837.31		920.73		803.07		1341.02		649.09	
Output Energy		28393.96		31940.34		31537.11		34707.52		27217.00	
Energy Indices:											
Energy Efficiency		2.78		5.20		2.18		4.40		2.58	
Energy productivity kg MJ^{-1}		0.08		0.15		0.06		0.13		0.08	
Specific Energy MJkg-1		12.20		6.48		15.73		7.73		13.13	
Net Energy		18177.10		25800.84		17052.85		26826.28		16673.88	

Table.7 Sources wise energy inputs used in the cultivation of chickpea using a traditional method

Sl. No	Particulars	M_2T_1		M_2T_2		M_2T_3		M_2T_4		M_2T_5	
		Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)	Inputs	Energy (MJ)
1	Human Labours (Hours)	354.04	693.92	401.94	787.80	333.77	654.20	410.02	803.64	338.14	662.76
2	Fuel (Lites)	10.21	574.83	11.39	641.31	9.63	542.24	12.81	721.47	9.25	520.87
3	Farm Machinery and Bullock Pairs (Hours)	281.99	1981.82	302.36	2146.48	255.82	1788.25	293.59	2181.35	271.36	2002.85
4	Chemical Fertilizers (Kg)	10.99	2032.52	8.24	2022.95	12.81	2104.26	7.75	2182.58	11.29	2520.92
5	Insecticides (Kg)	0.29	57.71	0.32	64.34	0.31	61.69	0.35	68.99	0.25	49.75
6	Seed (Kg)	54.33	798.70	52.67	774.20	56.00	823.20	57.33	842.80	52.33	769.30
Total Input Energy (MJ)		**6139.50**		**6437.08**		**5973.84**		**6800.84**		**6526.44**	
Grain Yield Kg ha^{-1}		946.80		1019.44		774.69		1052.21		833.49	
Output Energy		26472.44		45998.49		35713.36		22058.50		28701.18	
Energy Indices:											
Energy Efficiency		3.04		3.55		3.80		2.07		3.14	
Energy productivity kg MJ^{-1}		0.09		0.10		0.11		0.06		0.09	
Specific Energy MJkg-1		11.23		9.67		8.93		16.38		10.97	
Net Energy		17769.16		33027.14		26314.29		11423.56		19556.93	

Table.8 The field capacity of various operations under partial mechanized and traditional methods

Sl. No	Particulars of field operations	Field Capacity ha hr^{-1}									
		M_1T_1	M_1T_2	M_1T_3	M_1T_4	M_1T_5	M_2T_1	M_2T_2	M_2T_3	M_2T_4	M_2T_5
1.	Ploughing	0.30	0.31	0.33	0.26	0.33	0.30	0.27	0.31	0.24	0.34
2.	Compartment bunding	1.68	0.66	0.94	0.29	--	0.43	0.18	0.35	0.10	--
3.	Harrowing	0.36	0.36	0.55	0.31	0.48	0.06	0.06	0.07	0.07	0.06
4.	Sowing	0.33	0.39	0.31	0.27	0.31	0.19	0.21	0.25	0.11	0.12
5.	Intercultivation.										
	1stweeding	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
	2ndweeding	0.20	0.21	0.23	0.18	0.19	0.02	0.02	0.03	0.02	0.02
	3rd weeding	0.03	0.03	0.03	0.03	0.03					
6.	Insects and pest management										
	1stspraying	1.02	0.87	0.89	0.52	0.89	0.14	0.14	0.16	0.13	0.13
	2nd chemical spraying	1.01	0.52	0.81	0.51	0.78	0.14	0.13	0.14	0.13	0.12
7.	harvesting	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
8.	Threshing operation	**Field Capacity kg/hr**									
	Threshing	537.80	626.58	613.03	608.58	569.38	678.29	637.15	645.58	637.62	686.38

Table.9 Yield (kg ha^{-1}), rainwater use efficiency (kg ha^{-1} mm^{-1}), water productivity (Rs ha^{-1} mm^{-1}), and moisture conservation efficiency (%)

Treatments	Yield kg ha^{-1}	Stover yield kg ha^{-1}	Cost of cultivation (Rs)	Gross returns (Rs)	Net returns (Rs)	BC ratio
M_1T_1	837.31(ab)	1286.84 (ab)	14810 (bc)	31236 (ab)	16426 (ab)	2.11 (ab)
M_1T_2	920.73 (ab)	1440.19 (ab)	20394 (abc)	34386 (ab)	13992 (ab)	1.69 (b)
M_1T_3	803.07 (ab)	1232.95 (b)	13994 (bc)	29957 (ab)	15963 (ab)	2.14 (ab)
M_1T_4	1341.02 (a)	2102.84 (a)	16976 (abc)	47255 (a)	30279 (a)	2.78 (a)
M_1T_5	649.09 (b)	1001.35 (b)	11438 (c)	24220 (b)	12782 (b)	2.12 (ab)
M_2T_1	946.80 (ab)	1441.79 (ab)	23315 (ab)	35301 (ab)	11986 (b)	1.51 (b)
M_2T_2	1019.44 (ab)	1577.74 (ab)	24681 (a)	38048 (ab)	13367 (b)	1.54 (b)
M_2T_3	774.69 (b)	1206.76 (b)	20776 (abc)	28924 (b)	8148 (b)	1.39 (b)
M_2T_4	1052.21(ab)	1619.67 (ab)	25410 (a)	39257 (ab)	13847 (ab)	1.54 (b)
M_2T_5	833.49 (ab)	1315.91 (ab)	16051 (abc)	31146 (ab)	15095 (ab)	1.94 (b)
SEM±	20.23	31.26	434.77	754.48	871.60	0.06
CD	482.101	704.2	9846.14	17929.35	17330.9	0.84

Table.10 Yield (kg ha^{-1}), rainwater use efficiency (kg ha^{-1} mm^{-1}), water productivity (Rs ha^{-1} mm^{-1}), and moisture conservation efficiency (%)

Treatments	Yield (kg ha^{-1})	RWUE (kg ha^{-1} mm^{-1})	Water Productivity (kg ha^{-1} mm^{-1})	Moisture Conservation Efficiency (%)
M_1T_1	837.31(ab)	4.42ab	164.92ab	43.27 cd
M_1T_2	920.73 (ab)	4.86ab	181.55ab	52.68 b
M_1T_3	803.07 (ab)	4.24 b	158.17 b	51.05 b
M_1T_4	1341.02 (a)	7.08 a	264.47 a	64.84 a
M_1T_5	649.09 (b)	3.43 b	127.88 b	45.33 c
M_2T_1	946.80 (ab)	5.00ab	186.38ab	54.80 b
M_2T_2	1019.44 (ab)	5.38ab	200.88ab	40.85 cd
M_2T_3	774.69 (b)	4.09 b	152.72 b	63.38 a
M_2T_4	1052.21(ab)	5.56ab	207.27ab	62.58 a
M_2T_5	833.49 (ab)	4.40ab	164.45ab	39.10 d
SEM±	20.23	0.11	3.98	0.14
CD	482.101	2.54	94.66	3.71

Fig.1 Study area (Regional Agricultural Research Station, Vijayapura (Karnataka)

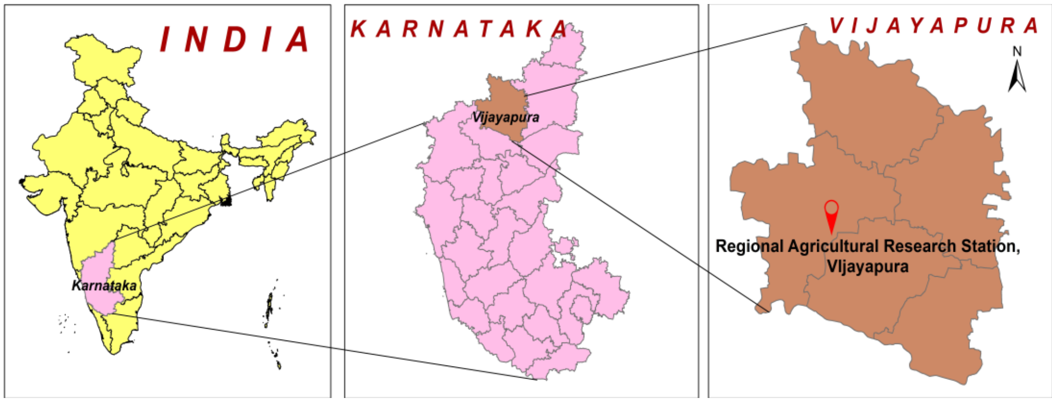


Figure 2: Compartment bunding using partial mechanized method

Figure 3: compartmental bunds using the traditional method

Figure 4 compartment bunding before rainfall

Figure 5 compartment bunding after rainfall

Fig.6 Rainfall (mm) and evaporation during a) 2017, b) 2018, and c) 2019

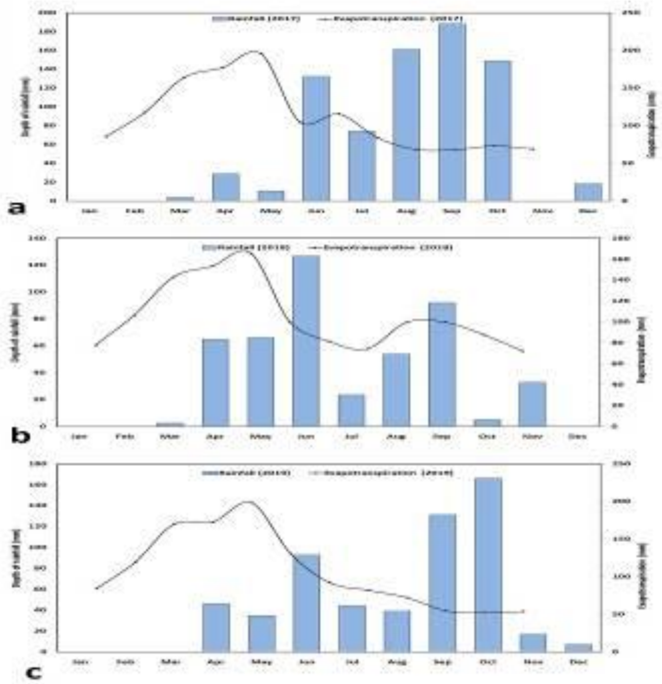


Fig.7 Sources-wise input used in a) M_1T_1, b)M_2T_1, c) M_1T_2, d)M_2T_2, e)M_1T_3, f)M_2T_3, g)M_1T_4, h)M_2T_4, i) M_1T_5, and j)M_2T_5

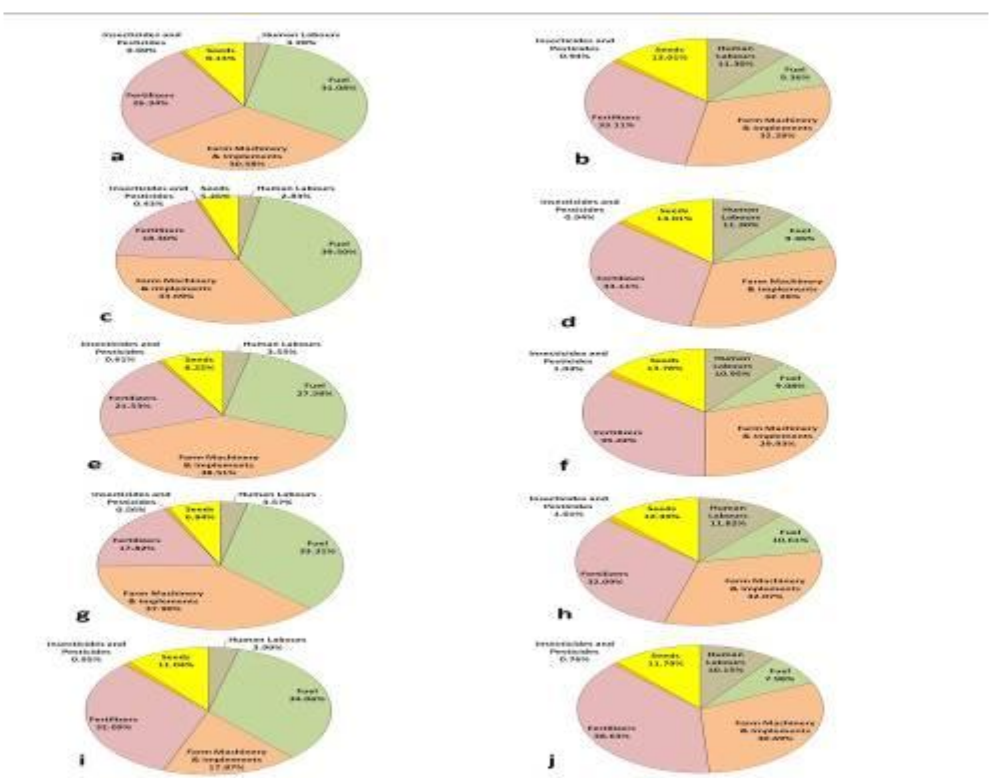
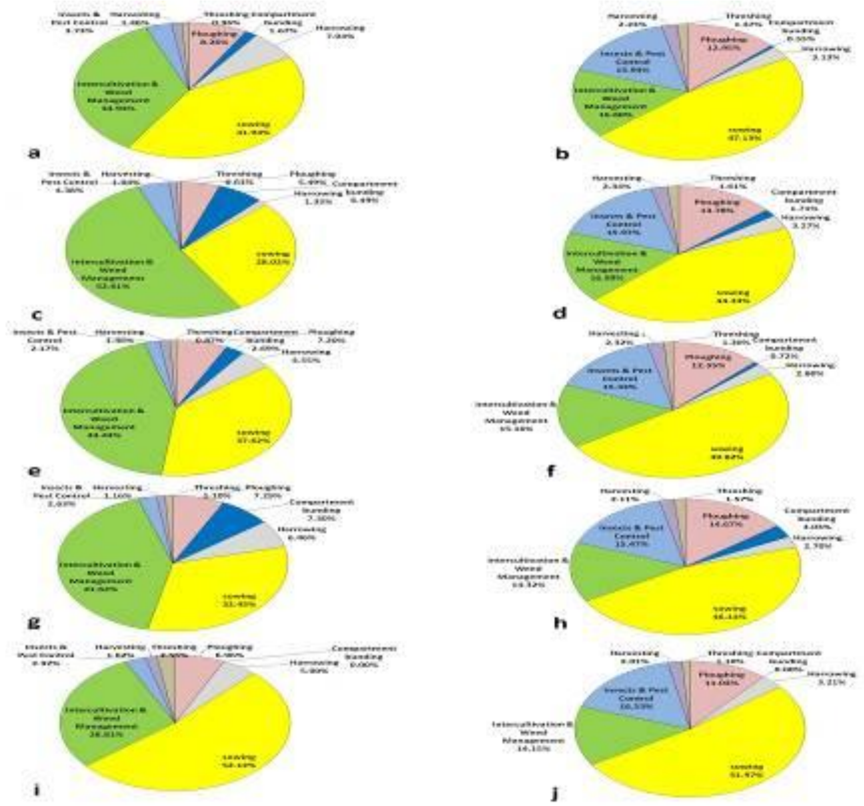


Fig.8 Operation-wise input used in a) M_1T_1, b)M_2T_1, c) M_1T_2, d)M_2T_2, e)M_1T_3, f)M_2T_3, g)M_1T_4, h)M_2T_4, i) M_1T_5, and j)M_2T_5



Economics

Assessment of partial mechanized and traditional cultivation and in-situ moisture conservation methods such as various sizes of compartment bunds were analyzed by using economic tools. these tools play a key role for the acceptance of aforesaid techniques by the farmers by seeing significant contribution of the methods as well as the sustainability of chickpea crop mainly depends on their performances of higher grain yield, byproduct, less input cost, less management and better market prices for the products under different climatic conditions (Patil *et al.*, 2014).

The higher gross returns of Rs 47255.00 ha^{-1} with a net return of Rs. 30279.00 ha^{-1} and B: C ratio of 2.78 was recorded under M_1T_4 of partial mechanized system. Whereas, lower gross returns of Rs. 24220.00 ha^{-1}, net returns Rs 12782.00 ha^{-1}, and B: C ratio of 2.12 was observed in M_1T_5. On the other hand, the highest gross return of Rs. 39257.00 ha^{-1}, net returns Rs 13847.00 ha^{-1} and B: C ratio of 1.54 was recorded in M_2T_4 in traditional cultivation method and lower gross returns of Rs 28924.00 ha^{-1}, net returns of Rs 8148.00 ha^{-1}, and B: C ratio of 1.39 was recorded in M_2T_3. Statistical analysis indicated that a significant increase in gross return and net return was observed in M_1T_4 of the partial mechanized system as compared to the traditional method. In addition to this, a significantly higher input cost was observed in the traditional system. Overall a significantly higher input cost was observed in M_2T_4 of the traditional cultivation method and a significant highest gross return, net returns, and B: C ratio was observed in M_1T_4 of the partial mechanized system of cultivation. This is due to the reduction of input cost and use of farm mechanization in the various operations and thereby it increases the overall economic benefits in terms of gross return, the net return, and the B: C ratio. Also, the water productivity in terms of economic benefits as compared to the traditional system and significantly higher water productivity of Rs 264.47 $ha^{-1}mm^{-1}$ was observed in M_1T_4 and lower water productivity of Rs 152.72 $ha^{-1}mm^{-1}$was recorded in M_2T_3.

Cultivation of chickpea along with the in-situ moisture conservation practices like the smaller size of compartment bund system i.e. 2x2*m* and 3x3*m* will help to increase the water productivity and use of farm mechanization to increase the field capacity during various farm operations and this helps to the farmer's to improve their standard of living by using mechanizations for in situ moisture conservation methods especially in Dry Land Agricultural regions. Therefore, that leads to improving the socio-economic status of the rainfed farmers.

In conclusion the conservation of in-situ soil moisture was an important parameter to increase crop productivity in rainfed areas of the Semi-Arid Tropical Region. The effect of compartmental bund of different sizes on Chickpea yield was assessed by using a partially mechanized method and traditional method of cultivation. The comportment bund size of 2x2m and 3x3m were found best practices for in-situ soil moisture conservation to increase grain yield, water use efficiency, and water productivity. Moreover, aforementioned compartment bund systems with the partial mechanized system will reduce input-cost, and thereby, it increases gross returns, net returns with higher B:C Ratio. In 2x2m compartment bund system with the partial mechanized method was observed that input energy of 12244.56 MJha-1 and net output energy 26826.28 MJha-1 with an energy efficiency of 4.40, energy productivity of 0.13 kg MJ-1, the specific energy of 7.73 MJkg-1 and 3x3m compartment bund size along with partial mechanized system energy input was 13625.01 MJha-1 and net output energy 25800.84 MJha-1 with energy efficiency was 5.20, energy productivity 0.15 kg MJ-1, the specific energy of 6.48 MJkg-1. In a 2x2m compartment bund system yield of 1341.02 kg ha-1 with input cost of Rs. 16976.00 ha-1 which gives the higher gross return of Rs. 47225.00 ha-1 and net return was Rs. 30279.00 ha-1 with a high B; C ratio of 2.78. The efficiency of the moisture conservation method was found highest of 64.84 percent with rainwater use efficiency of 7.08 kgha-1mm-1 and water productivity of Rs. 264.47 ha-1mm-1 in 2x2m compartment bund system under partial mechanized method. In addition, overall, 30 to 60 percentage of chickpea yield was achieved under 2x2m and 3x3m compartment bund systems under dryland condition will help farmers to continue cultivation practices in a sustainable manner in the rainfed region by using mechanization method along with in-situ moisture conservation methods.

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