Enhancing groundwater recharge and yield by adoption of continuous contour trenches in micro catchments

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ABSTRACT

In dryland agricultural sloping fields, whenever the rainfall event occurs, runoff begins and flows down from the slopes causing erosion. In such conditions, defined special measures can be adopted, which reduce runoff enabling the water to infiltrate down to the ground. Contour trenches are made mainly with this objective. The implementation of continuous contour trenches was done under various schemes *viz*. EGS, SGRY, RLEGP, DLFM, etc. in Maharashtra. To have definite quantification of conservation, recharge, soil moisture variations owing to acceptance of CCTs the research work was done on small catchment basis so that the appraisal and checking of CCTs is possible. It will be useful for researchers, field officers, farmers and NGOs. The study was conducted at the research field of the AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The catchment of 1.0 ha area was divided into two parts. One part is having CCTs and other kept as a control. The observations of LAI, soil moisture and groundwater level were collected. The Leaf Area Index (LAI) and interception component of seasonal crop and perennial plantations (Custard apple and Hanuman Phal) in a small catchment for the years 2022-23 and 2023-24 was observed to be highest at the flowering (3.67) and (3.61) stages, respectively. For perennial plantations, the LAI was observed highest at the developed fruit stages of the Custard apple and Hanuman phal. During both these years, canopy interception was also observed more in CCT adopted field compared to control field for seasonal and perennial plantations. The soil moisture was observed more in the catchment of CCT over control catchment. It was observed that by adoption of CCTs the groundwater recharge was increased by 20.51% over control (without CCT field). The acceptance of CCT resulted in yield increase of seasonal crop by 35.30% and yielding of fruits was more in CCT field by 49.10% over control.

Keywords: CCT, Dryland, Interception, LAI, recharge, yield.

1. INTRODUCTION

Catchment area can be envisioned based on the landscape/ topography and is the idea for designing soil and water conservation formations for water resources management (Kurothe *et al.*, 2014; Patode *et al.*, 2017). Based on field catchment, the runoff discharge be projected by taking into different factors (geographical and meteorological). This type of management involves the proportional utilization of NRM for optimizing invention with minimum jeopardy (Patode *et al.,* 2016). The partial arid regions with minimal intensity rainfall and poor soil coat produce high substance per unit area (Ramamohan Reddy *et al.*, 2013). Numerous interventions have obsessed the natural equilibrium, and agriculture has become a dominating factor in hastening land degradation. For *in-situ* conservation of soil and water, measures like CCTs were implemented to reduce soil loss, runoff and enable infiltration of water into the soil. To harvest runoff and sediment load, Continuous contour trench (CCT) is considered as one of the soil and water conservation structures (Bhange, *et al*., 2017). CCT technique should be used on large scale at wider part of Maharashtra to solve the soil and water conservation (Pendhare *et al.*, 2021). To know the impact of the conservation process, hydrological research wants to be conducted (Ramamohan Reddy *et al.*, 2013). Supervising agricultural field crops throughout the growing season is gradually more important to adjust the supervision and to specify knowledge for prediction yield at harvest time (Moharir *et al.,* 2021)). Field crop models and atmosphere-soil-vegetation process models are increasingly used for supervising activities. Nonetheless, it is hard for the models to interact for the spatial divergency in vegetation, soil conditions and the intrinsic difficulties of phenology modeling. Calibrating approach of the models using measurements of biophysical parameters may be the solution (Bondeau *et al.,* 1999; Launay and Guerif, 2005). A key variable for calibrating crop models is the LAI, which indicates leaf surface and is important because it is indexed in performing processes by allocating carbon to leaves. LAI also describes atmosphere-soil-vegetation interactions like photosynthesis, ET and biogenic emissions. During irrigation management, Leaf Index must exhibit the overland resistance when evaluating ET by directly applying Penman-Monteith's derived equation (Allen, 2000). Hydrological and ET models which depends on surface energy balance which consider the part of vegetation too require Leaf Index as input for separating evaporation and transpiration from ET (Norman *et al.,* 1995; Montaldo and Albertson, 2003; Hadria *et al.,* 2006). In modelling for assessment of soil moisture and groundwater recharge this observation are important. To have sustainability in perennial plantations and the advancement of water resources, the experiment was undertaken, and important observations are presented here.

2. material and methods

2.1 Study Area

The field experiment was conducted at AICRP dryland research field in Dr. PDKV, Agricultural University, Akola (Maharashtra), India. The location lies between latitude of 20° 43' 05.8" to 20° 43' 09.3" North and Longitude of 77° 02' 43.1" to 77° 02' 46.0" East with the elevation of 307m above MSL. It falls under the WVZ, part of the Central Maharashtra Plateau Agroclimatic zone. The total of 1 ha research site is shared into two catchments. The first catchment contains CCTs and plantations of Hanuman phal (*Anona atemoya*) and Sita phal (*Anona squamosa*). The crop was cultivated as an intercrop in a CCT plantation between two rows. The neighboring microsite was without measures of contour trenches and contains plants of *Anona atemoya* and *Anona squamosa*. The field crop of soybean was sown amongst the two rows of plantation of Custard apple and Atemoya during the *Kharif* season every year. The result of the existing CCTs in the micro catchment was assessed by analysing the appropriate components of the hydrological cycle. These outcomes were used for impact evaluation (Shinde, 2006; Pendke, 2009).

2.2 Soil moisture

A calibrated digital soil moisture meter was used to monitor the weekly volumetric soil moisture content in CCT treated as well as control micro-catchment.

2.3 Groundwater levels

Standpipe observation wells were constructed by installing plastic casing of 75mm diameter in a borehole of 100mm diameter. The plastic casing was put up to a depth of 12m and had 2mm diameter holes drilled over 2-12m depth. This is because the groundwater fluctuations were previously observed to be in the range of 2-10m. Sand gravels were placed between the borehole wall and the casing. Soil compaction was done at the ground surface pipe borehole interface. The located observation wells in MC-1 and MC-2 ware monitored for weekly groundwater levels by using the electrical water level indicator.

2.4 Estimation of LAI

The plants were grouped into small, large and medium for LAI estimation. The leaves of chosen plants were subdivided into medium, large and small litter materials. Shrubs (3) from every class were chosen, and a tally of small, medium and large vegetation was done and subdivided into the classes of medium, small and large category plants. The area of the plant materials was determined using Leaf area meter. Leaf canopy area was obtained and multiplied by all number of litter leaves in a particular group. Lastly, total area of litter material (leaves) was computed by counting the plant's medium, small and large leaves area. The LAI was then determined by dividing the area of leaves on the plants with area allocated to the plant (Row to plant spacing).

2.5 Interception component

The component (interception) is primarily based on Index of Leaves Area (Jensen, 1983). The type of vegetation, its development stage affects the intercepting water storage capacity (I_{max}) and is computed by:

… (1)

where, C_{int} = Parameter of interception, mm; and

LAI = Index of leaf area

The standard value of component, C_{int} is 0.05mm. Nonetheless, the precise value of component, C_{int} may be assessed from the calibration value. The LAI typically varies for unlike plantations from 0 to 5.

2.6 Assessment of CCT Performance

Performance of CCT adopted field over non CCT field was assessed by evaluating the relevant factors of the hydrological cycle. The results were utilized for the impact evaluation purpose. Besides this hydrological monitoring, the on-field observations and analysis of production of fruit was additionally used for evaluating CCT performance.

3. results and discussion

3.1 LAI and Interception component of crop and perennial plantation during 2022-23

The LAI and canopy interception data is given in Table 1. The LAI increased with crop growth, was maximum during the flowering (3.67) stages before declining as the crop grew older. At every stage of the crop's growth, the soybean crop planted in the CCT-treated catchment had a higher LAI than those planted in the untreated catchment. The maximum canopy interception was seen during the blooming stage of crop growth, and it was higher in soybean crops sown under the field of CCT adopted area compared to the area where CCT were not created. It was because the interception component function is directly related to the LAI. The observed data helps for setting up the MIKE-SHE model, and the hydrological model uses it to evaluate the ET component for crops.

Table 1. Growth stagewise LAI and canopy interception for soybean in the catchment during 2022-23.

Crop	Growth stages	LAI		Interception of Canopy, (mm)	
		CCT adopted	Without CCT adopted	CCT adopted	Without CCT adopted
Soybean	Initial growth	1.73	1.62	0.087	0.081
	Flowering initiation	2.89	2.69	0.145	0.135
	Flowering	3.67	3.54	0.184	0.177
	Pod initiation	3.60	3.39	0.180	0.170
	Pod development	2.31	2.18	0.116	0.109

Table 2 displays the data of LAI and canopy interception. It was found that the LAI increased with the plantation's growth and peaked when the Custard apple and Hanuman phal reached their fully mature fruit stages. LAI was greater in plantation of CCT adopted catchment than in untreated catchment at all crop growth stages. Since LAI was directly related to the function of interception component, the interception of plant canopy was highest during developed fruit stages and higher for plantations in the CCT-treated catchment than in the untreated catchment. As the LAI of CCT field is more there is more biomass incorporation, and it will be useful for increasing the soil fertility and ultimately results in good yield of crop and plantation in the CCT adopted catchment.

Table 2. Growth stage wise LAI and canopy interception of perennial plantation during 2022-23.

Growth stages	Leaf Area Index, LAI of Custard apple in catchment of		Leaf Area Index, LAI of Hanuman phal in catchment of		Canopy Interception for Custard apple (mm) in catchment of		Canopy Interception for Hanuman phal (mm) in catchment of	
	CCT	Non CCT	CCT	Non CCT	CCT	Non CCT	CCT	Non CCT
New leaves	0.15	0.13	1.02	0.89	0.01	0.01	0.05	0.04
Fruit initiation	2.62	2.41	3.36	3.16	0.13	0.12	0.17	0.16
Fruit development	3.59	3.45	4.66	4.4	0.18	0.17	0.23	0.22
Developed fruits	4.91	4.72	5.37	5.17	0.25	0.24	0.27	0.26
Maturity	3.82	3.53	5.06	4.89	0.19	0.18	0.25	0.24
Leaves shredding	2.84	2.46	3.51	3.29	0.14	0.12	0.18	0.16

3.2 LAI and Interception component of crop and perennial plantation during 2023-24

Table 3 displays the LAI and canopy interception data. It was inferred that the LAI increases with crop growth, reaching its maximum at the blooming (3.61) stages before declining as the crop reaches maturity. The LAI was higher in the soybean crop sown in CCT-treated catchment than in untreated catchment at every stage of crop growth. Given that the LAI and the interception component function are closely related, the maximum canopy interception was found during the blooming stage of crop growth, and it was higher in soybeans grown in catchments treated with CCT than in catchments not treated with CCT. Collecting year-wise LAI data and assessing the growth of field crop will help in building the crop growth model. With the results it can be inferred that the crop which was having higher LAI resulted in more yield. Thus, monitoring and estimation of LAI is essential and generated data can be directly used in hydrological models.

Table 3. Growth stagewise LAI and canopy interception for soybean sowed catchment during 2023.

Crop	Growth stages	LAI		Interception Canopy, (mm)	
		CCT adopted	Non CCT adopted	CCT adopted	Non CCT adopted
Soybean	Initial growth	1.67	1.63	0.084	0.082
	Flowering initiation	2.83	2.69	0.142	0.135
	Flowering	3.61	3.46	0.181	0.173
	Pod initiation	3.52	3.41	0.176	0.171

	Pod development	2.23	2.11	0.112	0.106

Table 4 displays the data on canopy interception and LAI. As the plantation grows, it was observed that the LAI increases, reaching its maximum at the matured fruit stages of the Hanuman phal and Custard apple. At every stage of crop growth, the leaf index was higher in the CCT treated catchment plantation than in the untreated catchment. Since the LAI is directly related to the component of interception, the plant canopy interception was highest during the developed fruit stages and higher for plantations in the CCT-treated catchment than in the untreated catchment. The litter of leaves which fall on the ground will develop the fertility and fruit production increases on such plantations as here in the case of Hanuman phal where the fruits production is much more over the control.

Table 4. Growth stage wise LAI and canopy interception of perennial plantation during 2023-24.

Growth stages	Leaf Area Index, LAI of Custard apple in catchment of		Leaf Area Index, LAI of Hanuman phal in catchment of		Canopy Interception for Custard apple (mm) in catchment of		Canopy Interception for Hanuman phal (mm) in catchment of	
	CCT	Non CCT	CCT	Non CCT	CCT	Non CCT	CCT	Non CCT
New leaves	0.13	0.12	1.00	0.89	0.01	0.01	0.05	0.04
Fruit initiation	2.54	2.38	3.31	3.17	0.13	0.12	0.17	0.16
Fruit developme nt	3.51	3.37	4.58	4.37	0.18	0.17	0.23	0.22
Developed fruits	4.84	4.65	5.29	5.12	0.24	0.23	0.26	0.26
Maturity	3.74	3.5	4.92	4.76	0.19	0.18	0.25	0.24
Leaves shredding	2.73	2.43	3.4	3.16	0.14	0.12	0.17	0.16

3.3 Yield of soybean seasonal crop (2022 and 2023)

The data of seasonal crop yield (soybean) is given in Table 5. It was observed that the total grain yield was more by 33% (2022) and 37% (2023) in field of CCT over control field. The average grain and straw yield data (Table 5) indicated that there was an increase of 35% and 36% in average grain and straw yield of soybean respectively in crop sowed in CCT catchment over the control catchment. Thus, the results advocates the farmers to adopt the continuous contour trenches in alternate land use systems and could go for cultivation of seasonal crops along with the usual perennial plantations.

Table 5. Average grain and straw yield of soybean

Treatment	Yield (kg ha^{-1}) during 2022-23		Yield (kg ha^{-1}) during 2023-24		Average yield of soybean (kg ha^{-1})		Increase in CCT site yield over control catchment	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control site (T_1)	1095	1292	1117	1306	1106	1299	-	-
CCT site (T_2)	1460	1740	1533	1809	1497	1775	35.30	36.60

3.4 Yield of perennial plantations (2022 and 2023)

The data of fruits obtained from the plantations are given in Table 6. It was observed that the total yield was more by 54.28% and 48.00% (2022) and 46.15% and 48.38% (2023) in field of CCT over control field for Sita phal and Atemoya respectively. The average fruit yield data is given in Table 7. It was observed that the average yield of fruit is more by 50% and 48.21% respectively for custard apple and Atemoya. The idea of any catchment management is to have more yield per unit area of land. In alternate land use system, the in-situ conservation measures like continuous contour trenches holds great promise as a moisture conservation method and helps in improving overall soil status and thereby the production of fruits in CCT field is more over normal fields. This will become a source of income generation for farmers and small land holders. Here in this study the alternate land becomes useful by adoption of CCT measures and resulted in establishing the good plantations in dryland conditions. If farmers adopt these techniques, then establishment of fruit plantations is possible in Dryland conditions providing additional source of income besides other benefits.

Table 6. Production of Custard apple and Atemoya (Hanuman Phal) during 2022-23 and 2023-24

Picking of fruits	2022-23				2023-24			
	Weight of Custard apple (kg)		Weight of Atemoya (kg)		Weight of Custard apple (kg)		Weight of Atemoya (kg)	
	CCT site	control	CCT site	control	CCT site	control	CCT site	control
I	13.0	7.0	9.0	8.0	15.0	8.0	10.0	6.0
II	15.0	10.0	9.0	6.0	16.0	11.0	12.0	9.0
III	16.0	11.0	10.0	7.0	14.0	12.0	13.0	9.0
IV	10.0	7.0	9.0	4.0	12.0	8.0	11.0	7.0
Total	**54.00**	**35.00**	**37.00**	**25.00**	**57.00**	**39.00**	**46.00**	**31.00**

Table 7. Increase in fruit yield of CCT site catchment of Custard apple and Atemoya (Hanuman Phal) over control catchment during 2022-23 and 2023-24

Picking of fruits	Average Weight of Custard apple (kg)		Average Weight of Atemoya (kg)	
	CCT site	control	CCT site	control

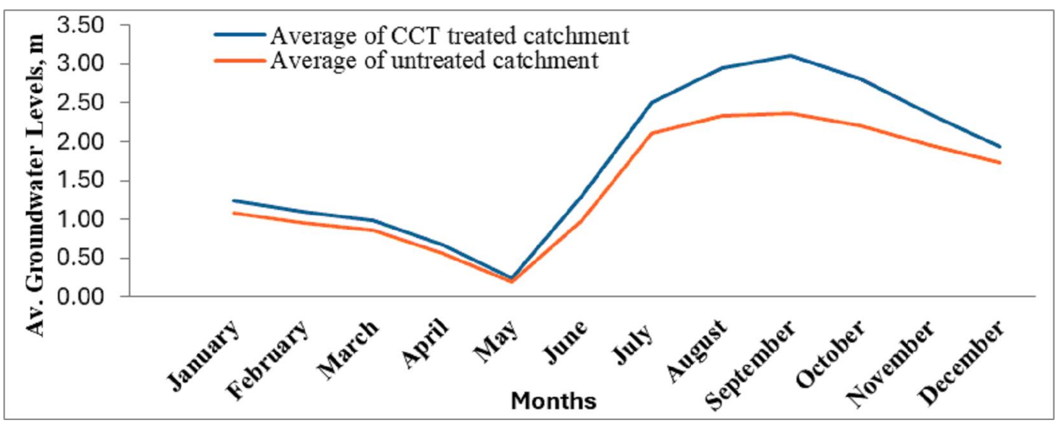
I	14	7.5	9.5	7
II	15.5	10.5	10.5	7.5
III	15	11.5	11.5	8
IV	11	7.5	10	5.5
Total	55.5	37	41.5	28
Increase over CCT site over control (%)	50.00	-	48.21	-

3.5 Soil Moisture (2022-23 and 2023-24)

Observed soil moisture at different depths (0-15, 15-30 and 30-45cm) for the years 2022-23 and 2023-24 is presented in Fig. 1 and 2 respectively. The soil moisture status in catchment of CCT was observed to be superior as compared to the control site during recorded month. The continued moisture in the site of CCT has enhanced the growth of regular plantation of *Annona squamosa* (Custard Apple) and *Annona atemoya*. This increased soil moisture content helps in developing larger plant canopy resulting the higher yield of field crop and that of perennial plantation in the catchment area of CCT over control field. The quantification of soil moisture content will help for data generation of unsaturated zone in the modelling processes.

Fig. 1. Soil moisture at various depths in control and CCT field recorded in different months during 2022

Fig. 2. Soil moisture at various depths in control and CCT field recorded in different months during 2023



3.6 Ground water levels (2022)

The fluctuations during 2022 from the monitored observation wells are presented in Fig. 3 and Fig. 4 respectively. It was observed that the fluctuations (%) in groundwater levels of CCT site over control field were higher in June (31.82%) followed by September (31.22%) and October (26.70%). The GWL were more in CCT site compared to control site. The groundwater recharge in CCT catchment was more by 21.32% over control catchment and indicates the advantages of CCTs for groundwater recharge in small fields. Looking to climate change scenario and uneven distribution of rainfall, in-situ water conservation techniques must be adopted for more groundwater recharge. Through quantification data it can be inferred that CCT are helpful in higher recharge. Hence in dryland agriculture where the slope is more than 3% and in alternate land use systems the CCTs proved to be helpful conservation measures.

Fig. 3. GWL in different months in the micro catchment during 2022

Fig. 4. Increase in groundwater levels in CCT treated micro-catchment over control during 2022

3.7 Ground water levels (2023)

The groundwater fluctuations during 2023 are presented in Fig. 5 and Fig.6 respectively. It was observed that the fluctuations (%) in groundwater levels of CCT site over control field were higher June (26.78%) followed by September (25.22%). The GWL were more in CCT site compared to control site. The groundwater recharge in CCT catchment was more by 20.41% over control catchment. In small fields during entire summer season the unsaturated zone becomes completely dry. When the monsoon rain comes the unsaturated zone started becoming saturated. In hydrological modelling the observed data of groundwater levels is important for validation of the results. With the available data the water table of the area can be known, and accordingly further planning is possible and therefore monitoring of observation wells on micro-catchment basis is important. Here the obtained results justify the use of CCTs for increasing the groundwater recharge and contribution of more water to saturated zone.

Fig. 5. GWL in different months in the micro catchment during 2023

Fig. 6. Increase in groundwater levels in CCT treated micro-catchment over control during 2023

In CCT treated micro-catchment, the observed and simulated average depth to phreatic surface during earlier study for wells with statistical performance criteria, i.e., mean error (ME) and Nash-Sutcliffe coefficient (R^2) revels that ME varies between -0.12 and -0.15, whereas R^2 statistics remains close to one. This shows that the simulated groundwater levels match the observed ones quite well.

4. Conclusion

It can be inferred that, when compared to untreated treatment, in-situ conservation measures (CCTs) were found to be beneficial for crop growth and development of fruit plantations. The LAI and interception component data can be used to build any hydrological or crop growth model. Performance assessment of the prevailing CCT illustrate that its acceptance consequences in upsurge in yield of seasonal (soybean) crop and the production of fruits are increased in CCT adopted area related to control field in Sita phal (Custard apple) and Hanuman phal (Atemoya) plantation. The groundwater recharge enhancement by 20.51% in CCT field over control would be possible. In general, it would be concluded that the CCTs are beneficial in less rainfall areas for moisture generation and runoff conservation. Furthermore, the CCTs would be effective measures to development of non-arable lands. In higher rainfall zones it will act as a drain for draining the excess runoff out of field ultimately avoiding waterlogging.

5. IMPLICATIONS

In fact, it is suggested that every piece of land should be treated as a micro-catchment and accordingly the conservation measures like CCTs should be adopted. Here in this research, both the micro-catchments were confined into micro-watersheds since they are bounded by one unit with bunds all along the boundaries so that water can passes through single outlet. Here the area of each micro-catchment is very small. Therefore, the increase in groundwater recharge was observed less. If the CCT treated field is compared with open field, then the observed impact assessment will be more in respect of groundwater recharge and other parameters.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies are used.

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