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Effects of Crop Canopy and Rainfall Intensities on Runoff in *Alfisols* of Eastern Dry Zone of Karnataka

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Dryland ecosystems are highly susceptible to water and wind erosion due to the lack of vegetation on the soil surface. Plant and residue cover act as a protective shield, slowing down runoff and allowing water to infiltrate. The right crop selection, considering rainfall intensity, market demand,

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and resources, is crucial for soil and water conservation in dryland agriculture. Crops with good biomass, canopy cover, and extensive root systems effectively protect against erosion and reduce nutrient loss. Intercropping enhances soil coverage and shields the soil from raindrop impact. To address these issues, a study aimed to identify suitable crops and cropping systems in the Eastern Dry Zone of Karnataka, focusing on the relationship between rainfall characteristics, crop canopy cover, and runoff during different growth stages. The experiment included five open field plots totaling 20,304 m²: T_1 (Pomelo) - 3,226 m², T_2 (Castor) - 5,255 m², T_3 (Pigeon pea) - 5,585 m², T_4 (Chickpea) - 5,998 m², and T_5 (control, no crop) - 240 m². Among the treatments, Pomelo (T_1) had the lowest runoff of 5.33%, with substantial canopy cover (11.66 m²/tree). Castor (T_2) recorded 7.23% runoff with 0.37 m²/plant cover, Pigeon pea (T_3) had 8.44% with 0.34 m²/plant, Chickpea (T_4) had 11.94% with the least cover (0.01 m²/plant) and Control (T_5) with no crop cover had a 17.43% of runoff. The statistical analysis of the parameter was subjected to one factor CRD analysis and the results are significant with respect to crop canopy cover and runoff. The results showed that higher canopy cover effectively intercepts rainwater, allowing for better infiltration and reduced runoff. From a soil health perspective, T_1 (Pomelo) was the most effective at minimizing runoff and retaining moisture during dry spells.

Keywords: Runoff; crop canopy; cropping period; rainfall and intensity.

1. INTRODUCTION

The movement of water and moisture globally, including plant life and the atmosphere, is crucial for the health of humans, flora, and fauna. By evaluating water input and output in a watershed for rainwater management in red soils of dryland regions is very important and water requirement for different human activities particularly in agriculture sector is a crucial and need of the hour which may help to develop low cost location specific socially acceptable strategies for various crops and terrains in the country and state as well. Understanding land use impacts on water balance and runoff remains a key focus in hydrological research may also helping to predict future water availability for agriculture [1,2]. The systematic estimation and determination of rain water interventions and requirements in drylands as a first step in establishing improved approaches or techniques and tools for influencing policy in water management in drylands. Biological conservation methods are increasingly recognized for their long-term effectiveness and cost-efficiency under dryland areas by developing dense plant hedges with shallow roots reduce velocity of water flow, increasing time of concentration, enhance infiltration, and evenly distribute soil moisture in micro-watersheds apart from boosting crop yields [3]. Vegetation protects soil from raindrop impact reduce the detachment of soil particles from the soil mass held soil particles tightly by the roots of grass which improves infiltration rate, soil water content, structure, and stability, creating durable macropores [4]. Studies show that increased tree/crop canopy can reduce runoff by up to 62% and the selected suitable land use systems were implemented with conservation measures is essential for cost-effective, location-specific farming practices [5]. Tree canopies significantly reduce soil erosion and runoff by intercepting rainfall, with agri-horti systems increasing infiltration and agro-forestry reducing runoff [6]. In the face of climate change and growing demands on agriculture, identifying effective cropping strategies is vital for improving soil health and ensuring sustainable production. By examining the relationship between rainfall, canopy cover, and runoff in areas like the Eastern Dry Zone of Karnataka, this research can reveal how crops with deep roots and good biomass can prevent erosion. Additionally, intercropping and residue management help protect soil from rain impact and retain moisture. These findings will promote resilient farming, reduce land degradation, and help the farmers to adopt sustainable, economically viable practices.

2. MATERIALS AND METHODS

During *Kharif* season of 2022 (May to December), a field experiment was carried out at All India Co-Ordinated Research Project for Dryland Agriculture, University of Agricultural Sciences, Bangalore aimed to study and develop the relationship between rainfall characteristics and runoff under various land surface conditions in red sandy loam soil of Eastern Dry Zone of Karnataka. The rainfall data was collected using a specialized self-recording rain gauge installed at the Meteorological station of the Dryland Agriculture Project in Bengaluru. The farm ponds are constructed with brick lining materials and are located at the downstream section of each plot. The dimensions and volume of water that can be stored in each farm pond is presented in Table.1. Where, Pond – 1 (P_1), Pond – 2 (P_2), Pond – 3(P_3), Pond – 4(P_4) and Pond – 5 (P_5) represents the ponds with different treatments viz., Pomelo (T_1), Castor (T_2), Pigeon pea (T_3), Chickpea (T_4) and control (T_5) respectively.

2.1 Location of the Experimental Site

The geographical coordinates of the research site are approximately 13°5' North latitude and 77°34' East longitude, with an elevation of 924 meters above mean sea level. The experimental location falls within the Eastern Dry Zone (Zone – V) of the Agro-climatic zone of Karnataka.Fig.1. represents the location of the study area.

2.2 Actual Climatic Conditions

During 2022, the total rainfall of 1556.8 mm of was received and recorded at meteorological station located adjacent to experimental site. The other important weather parameters such as average maximum temperatures ranged from 25.2ºC to 33.5ºC, and minimum temperatures ranged from 14.8ºC to 20.1ºC, monthly relative humidity averaged 81% in March to 91% in August. The bright sunshine hours peaked in February (8.7 hrs) and were lowest in July (3.4 hrs) with an average wind speed varied from 3.5 to 6.0 km/hr during the experimental period and open pan evaporation peaking in April (7.1 mm/day) and lowest in July (3.1 mm/day).

2.3 Soil and its Characteristics

Soil samples were collected from five treatments, with eight sub samples taken from each treatment at a depth of 0-15 cm. The soil was classified as red sandy loam, well-drained, slightly acidic with a pH of 5.11, and had an electrical conductivity of 0.04 dS/m. The soil contained 0.37% organic matter and exhibited a maximum water holding capacity of 33.61%.

2.4 Details of Experiments

The experiment investigated runoff in relation to crop canopy growth stages and rainfall intensity to establish a rainfall-runoff relationship. The study involved five plots covering a total area of 20,304 m². These plots included: T_1 (Pomelo) with an area of 3,226 m², T_2 (Castor) with 5,255 m², T_3 (Pigeon pea) with 5,585 m², T_4 (Chickpea) with 5,998 m², and T_5 (control, no crop) with 240 m². Due to the varying sizes of the plots, the actual experimental area was standardized, and runoff was computed on a per-unit-area basis, i.e., runoff per hectare. The layout of the experimental plots and location of the farm pond is shown in Fig.2.

2.5 Runoff Measurement

The runoff from individual plots collected into the farm pond located at the downstream section of the each treatment measured by taking depth of runoff water collected in the farm pond for each runoff event from each treatment and when the overflow occurred, the amount of overflow was recorded by the automatic stage level recorder, installed at the outlet of the farm pond and volume of overflowed runoff water from the farm pond determined by analyzing hydrograph generated for each overflow water from farm pond and the same is added to obtain total runoff.

2.6 Volume of Farm Pond

The volume of a farm pond can be calculated using Simpson's formula, which is particularly useful for determining volumes with varying cross-sectional areas. According to the formula, the volume is given by:

$$\text{Volume of farm pond } = \frac{A+4B+C}{6} \times D \qquad \text{(i)}$$

In this equation, A represents the top area of the pond (m²), C is the bottom area (m²), and B is the middle area (m²). The variable D corresponds to the depth of the pond (m). The formula provides an accurate estimation by considering the varying areas at different depths within the pond, offering a more precise calculation than simple averaging methods [7].

$$\text{Runoff (mm)} = \frac{\text{Volume (m3)}}{Catchment\ area\ (m2)} \times 100 \qquad \text{(ii)}$$

$$\text{Runoff (\%)} = \frac{\text{Runoff (mm)}}{Rainfall(mm)} \times 100 \qquad \text{(iii)}$$

2.7 Rainwater Directly Falling on Farm Pond

$$\text{Rainwater directly falling on farm pond (mm)} = \frac{Rainwater\ directly\ collected\ in\ farmpond\ (m3)\ X\ 1000}{cross\ sectional\ area\ of\ the\ farmpond\ (m2)} \qquad \text{(iv)}$$

2.8 Density of Vegetation

$$\text{Plant/ Tree density (Plants /ha)} = \frac{10000}{(Row\ to\ Row\ spacing)\ \text{X}\ (\ Plant\ to\ plant\ spacing)} \qquad \text{(v)}$$

Table 1. Detailed information of farm pond and its dimensions

Farm Pond No.	Farm Pond Size				Depth (m)	Volume (cum)	Farm pond side slope V:H	Soil Type	Lining	Catchment area (m^2)
	Top Width (m)		Bottom Width (m)							
	L	W	L	W						
P_1	9.0	9.0	3.0	3.0	3	117	1:1	*Alfisols*	Brick lining	3226 m^2
P_2	10.5	10.5	4.5	4.5		180		Red Sandy	Brick lining	5255 m^2
P_3	10.5	10.5	4.5	4.5		180		loam	Brick lining	5585 m^2
P_4	10.5	10.5	4.5	4.5		180			Brick lining	5998 m^2
P_5	10.5	10.5	4.5	4.5		180			Brick lining	240 m^2

V:H = Vertical to horizontal

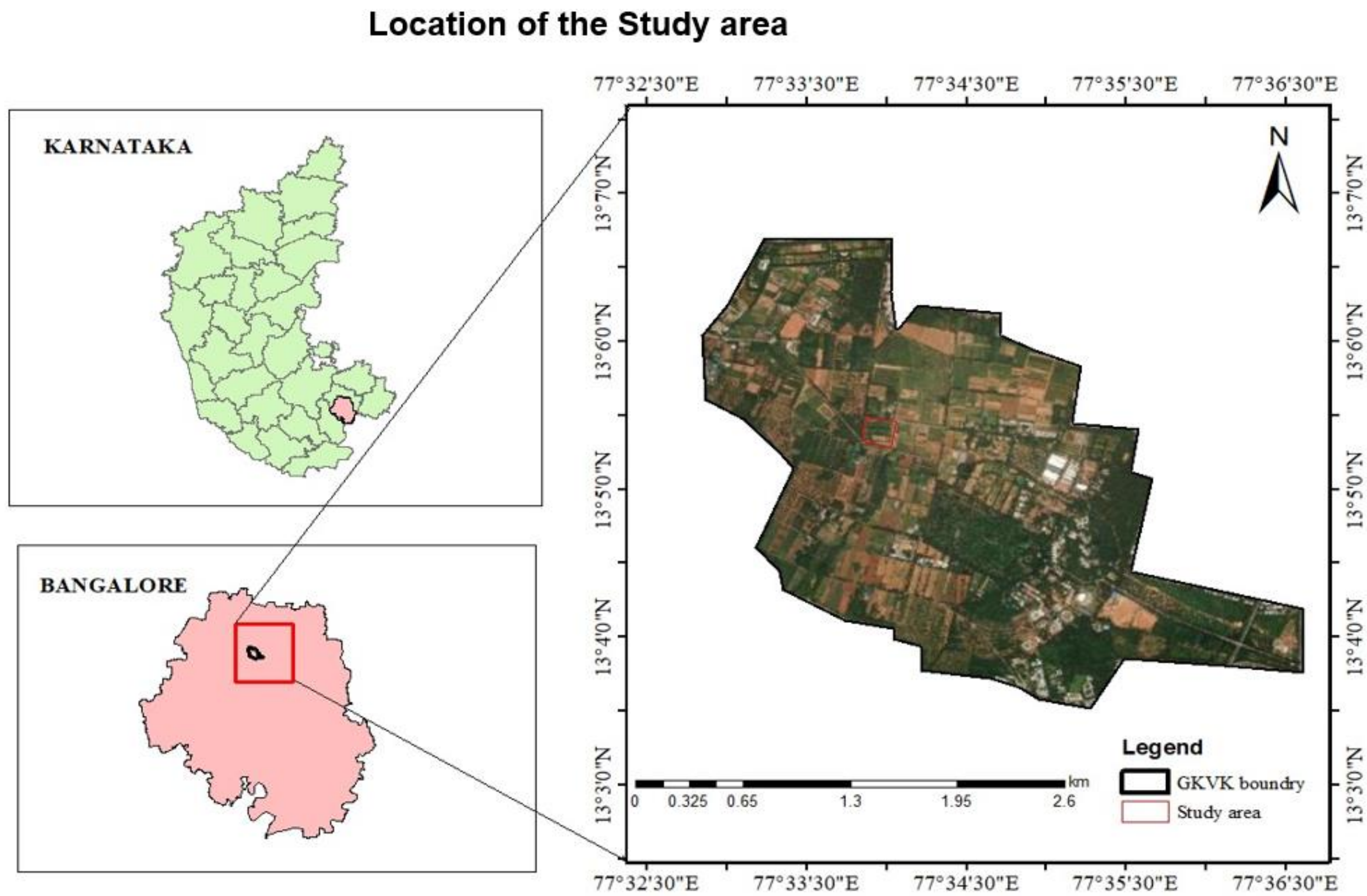

Fig. 1. Location of the study area

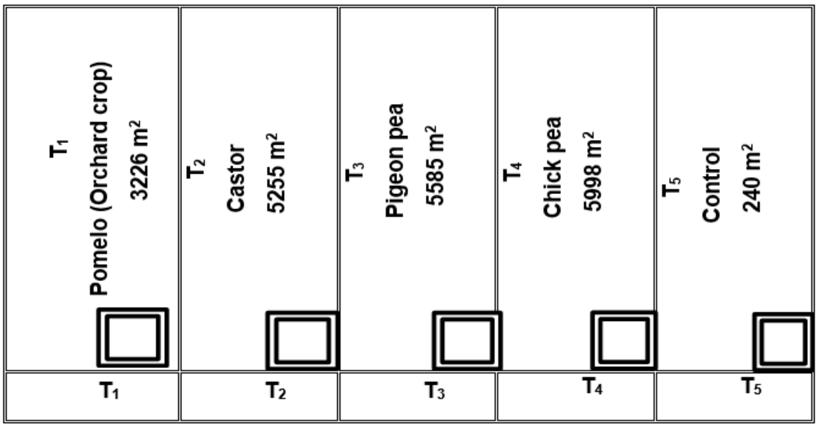

Fig. 2. Plan and layout of experimental site

2.9 Crop Canopy Spread Area (cm^2)

$$Plant\ spread\ (cm2) = East - West\ (cm)\ X\ \ North - South\ (cm) \qquad \text{(vi)}$$

3. RESULTS AND DISCUSSION

3.1 Relationship between Rainfall and Runoff

In 2022, there were 75 rainy days with a total rainfall of 1556.8 mm, exceeding the normal 941.4 mm. Most of the rainfall (1490.8 mm) occurred from May to December over 71 days, with 34 runoff events. The highest single-day rainfall was 130 mm in May, causing the greatest runoff (14.42%) in the control plot (T_5). Another significant event in June led to runoff, with T_5 again having the highest (13.80%) Fig.3. represents total rainfall occurred during the experimental year.

3.2 Rain Water (mm) Directly Fall on Farm Pond and Collected in Water Storage Structures

Rain water directly falling on the farm ponds for each rainfall events causing runoff under various treatments are determined for quantifying the actual amount of runoff produced for each event during the cropping season and the data presented in Fig.4.

Throughout the entire cropping season, the most substantial rainfall occurred in May 2022, with a record of 130.0 mm rainfall. This led to the direct collection of rainwater measured in cubic meters amounting to 1.05 mm in T_1 and 1.43 mm in T_2, T_3, T_4, and T_5. Following closely, the second-highest rainfall of 104.8 mm in June, 2022, resulted in the direct collection of rainwater totaling 0.85 mm in T_1 and 1.16 mm in T_2, T_3, T_4, and T_5. A total of 9.31 mm in T_1 and 12.69 mm was collected in T_2, T_3, T_4, and T_5 farm ponds as throughfall during the entire period of cropping season. As inferred by Ramos Hernandez et al. [8].

3.3 Actual Runoff (mm) under Different Treatments

During the crop season from May to December 2022, there were 34 runoff events across treatments. The highest rainfall, was in the month of October, resulted in runoff ranging from 7.10% to 24.13% across treatments. And second highest rainfall was observed in the month of June, led to runoff ranging from 5.03% to 13.80%. The minimum rainfall was in the month of November resulted in runoff ranging from 0.43% to 20.40%. Throughout the season, the Control plot (T_5) had the highest runoff of 17.43%, while the Pomelo plot (T_1) had the lowest runoff of 5.33% as observed by English et al. [9]. Further Fig. 5. shows the relationship between rainfall and runoff under different treatments during the cropping period, 2022.

3.4 Runoff as Influenced by Rainfall Characteristics under Different Treatments

In the experimental plots, the highest recorded rainfall of 130 mm in May and 104.8 mm in June with an intensity of 80 mm/hr resulted in the highest runoff while the smallest rainfall of 7 mm in November, with an intensity of 14 mm/hr, resulted in minimal runoff. The highest rainfall intensity resulted in higher runoff contribution from the treatments the results aligned with findings of Zhang J et al. [10]; Duan G et al. [11]. Fig. 6. shows the effect of runoff as influenced by the rainfall characteristics under different treatments.

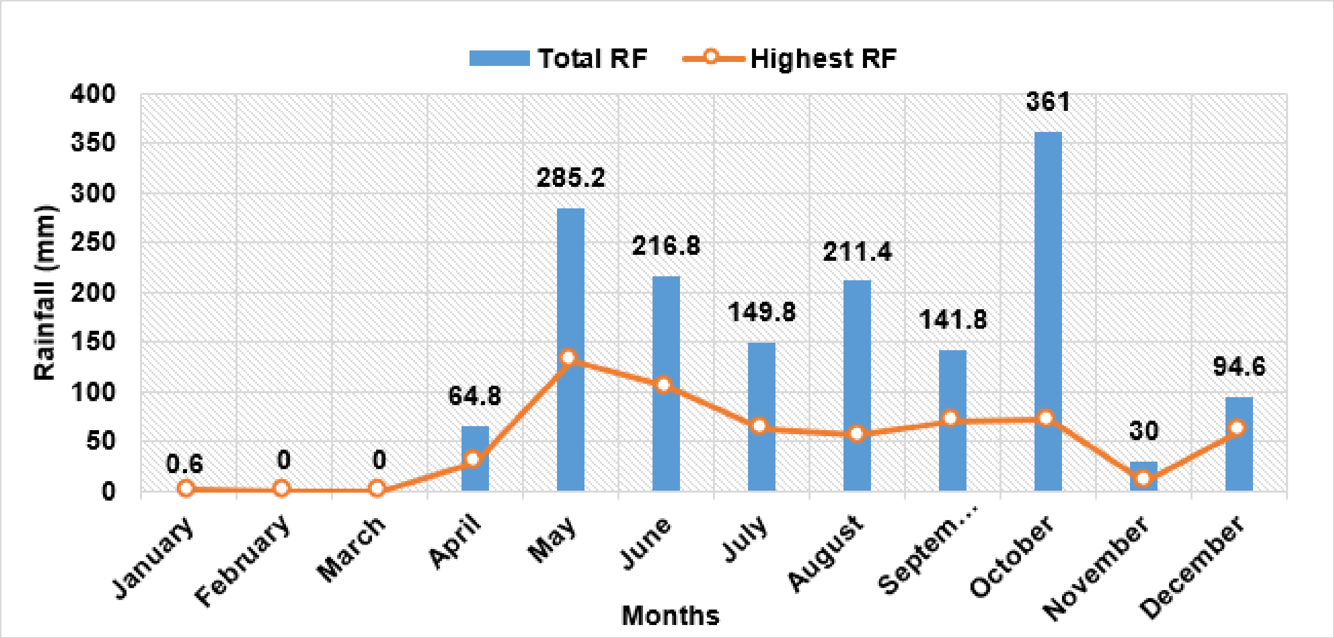

Fig. 3. Total rainfall during the experimental year

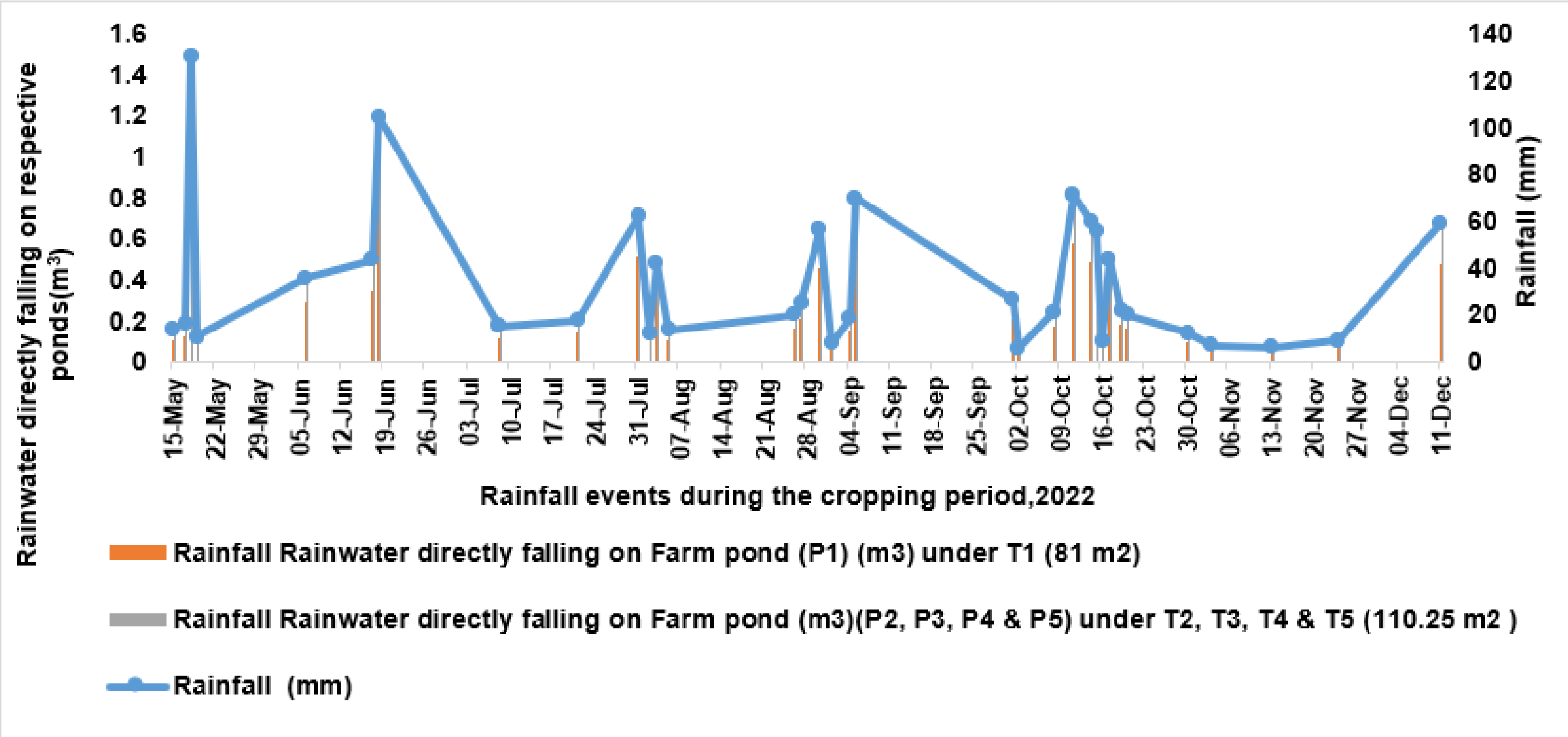

Fig. 4. Rain water directly falling on the farm ponds for respective rainfall events under various treatments

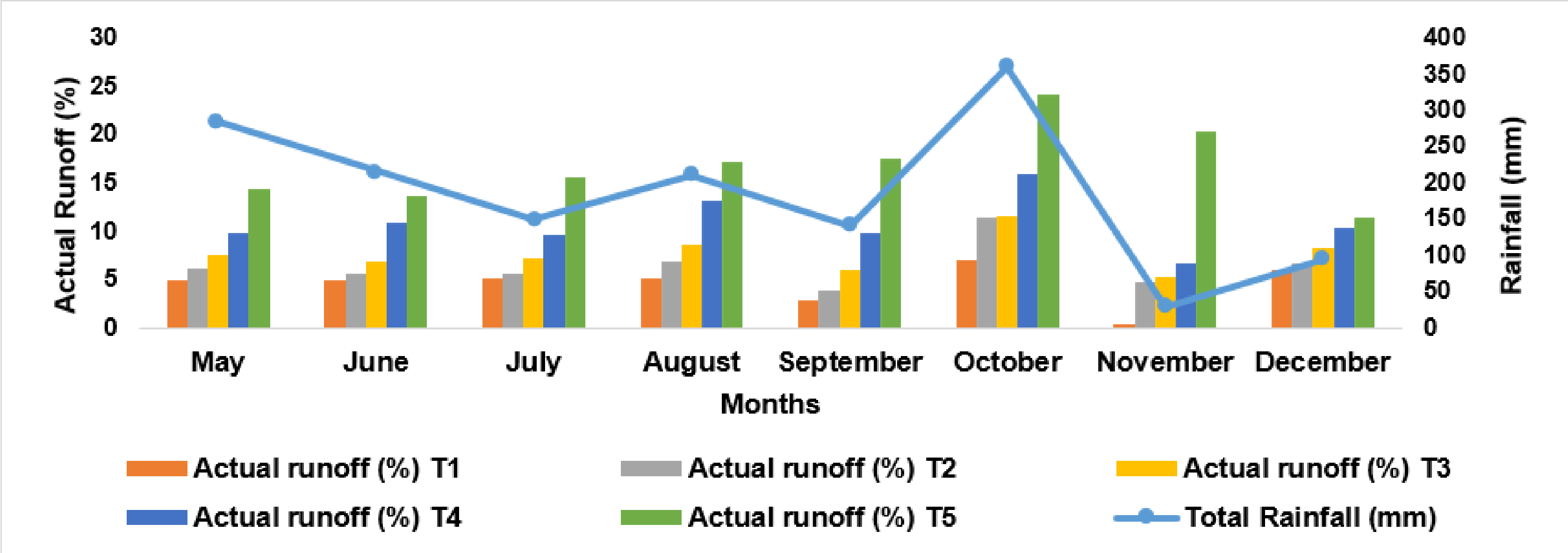

Fig. 5. Relationship between rainfall and runoff under different treatments during the cropping period,2022

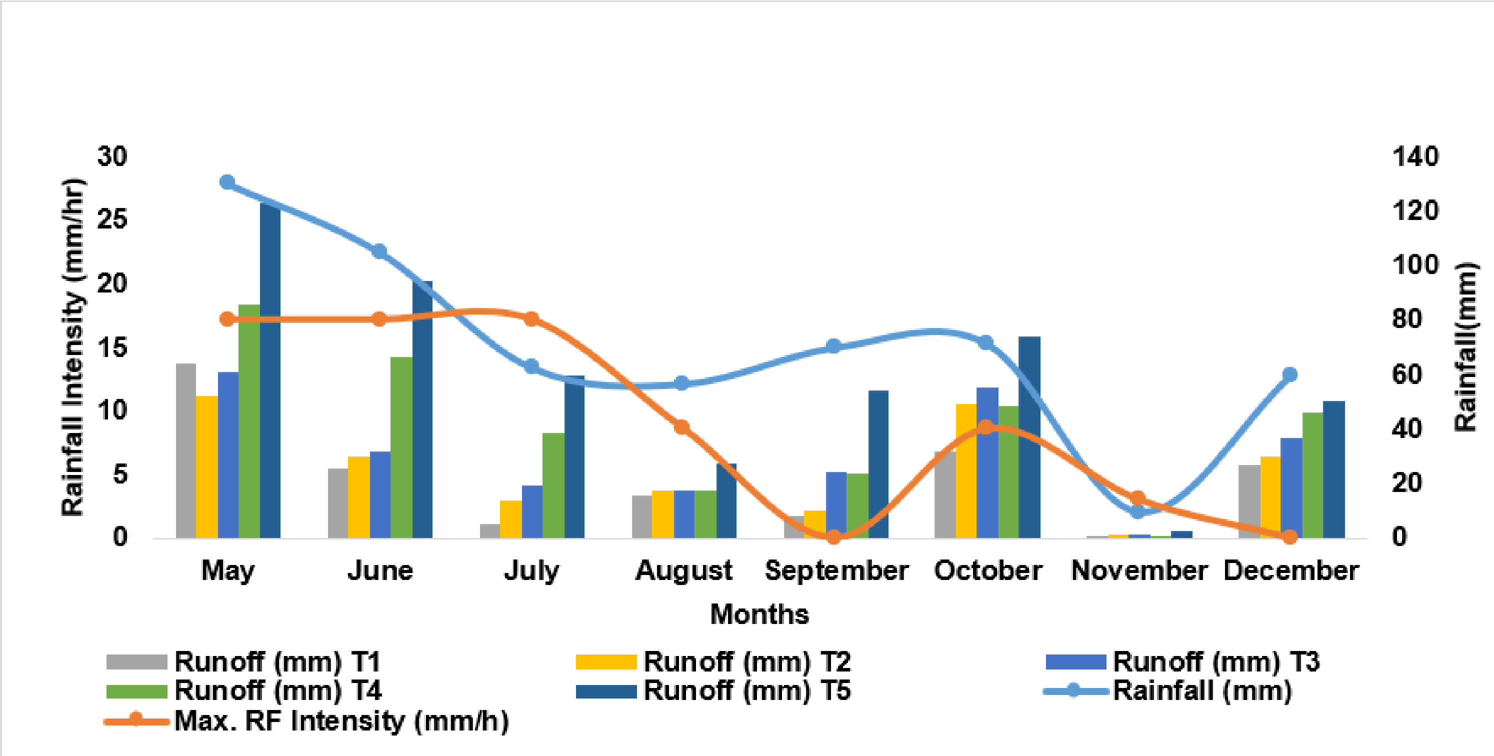

Fig. 6. Effect of runoff as influenced by the rainfall characteristics under different treatments

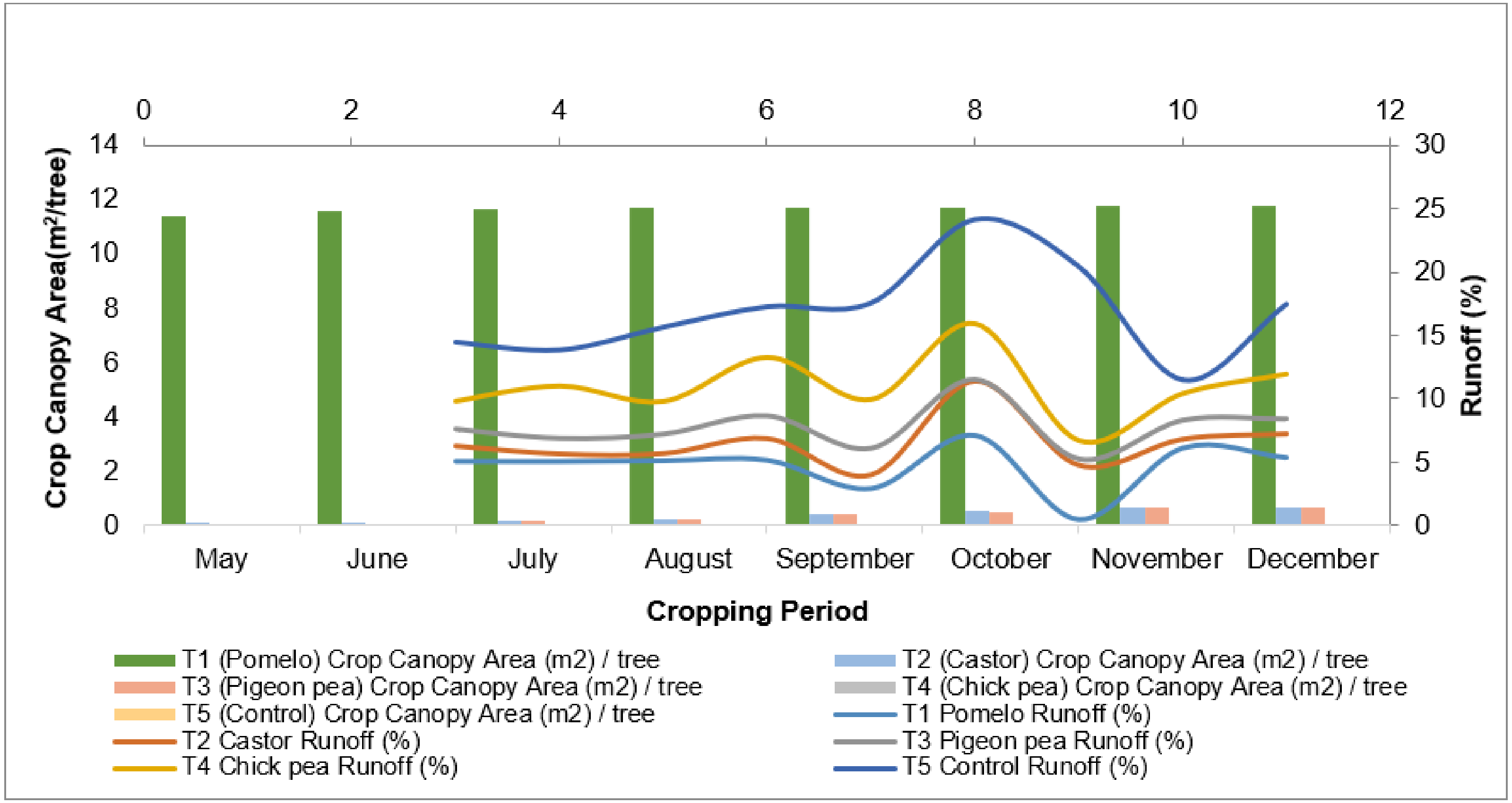

Fig. 7. Runoff variations among the treatments during different stages of cropping period

3.5 Stages of Crop Growth as Influenced by Runoff

Crop growth is affected by climatic factors, especially rainfall patterns in rain fed agriculture. Fig. 7. illustrate runoff variations among treatments during different stages of cropping period. November had the least runoff, with Pomelo (T_1) having 0.43%, followed by Castor (T_2), Pigeon pea (T_3), Chickpea (T_4), and Control (T_5). Canopy size differences explain runoff variances; results are consistent with Kang et al. [12]; Zhu et al. [13].

The study indicated that the percentage of runoff to monthly rainfall in different treatments stated that the Control (T_5) plot had the highest runoff percentage in October (24.13%), while Pomelo (T_1) had the lowest in November (0.43%). The runoff trend followed Pomelo < Castor < Pigeon pea < Chickpea < Control. The results of the study confirmed with the presence of ground vegetation water flow retards and extends soil seepage time, consistent conducted by Sharma et al. [14]; Singh et al. [15].

In the plots, Control (T_5) had the highest runoff of 17.43% due to lack of canopy cover, while Pomelo (T_1) had the lowest runoff of 5.33%, correlating with its substantial canopy cover (11.66 m^2/tree). Castor (T_2) had runoff of 7.23% with 0.37 m^2/plant canopy cover, Pigeon pea (T_3) had 8.44% runoff with 0.34 m^2/plant canopy cover, and Chickpea (T_4) had 11.94% runoff with the least canopy coverage (0.01 m^2/plant) aligned with Ding et al. (2022).

The crop canopy coverage in between the treatments has a significant change which resulted in higher canopy cover crop and has a less runoff when compared to least canopy cover crop, this decrease in runoff is due to the presence of dense vegetation, which slows down the speed of runoff, providing more opportunity time for rainwater to infiltrate into the soil as observed by Machiwal et al. [16]. The crop canopy cover area trend is in the order of Control (T_5) < Chickpea (T_4) < Pigeon pea (T_3) < Castor (T_4) and < Pomelo (T_1). The results of the study are on par with the result of the study conducted by Vasquez mendez. R et al. [17]; Liu Jinbo et al. [18].

4. CONCLUSION

This research is vital for future exploration due to its relevance to sustainable water management and soil conservation in rain-fed agriculture, especially in the face of climate change. Increasingly erratic rainfall patterns lead to significant runoff and soil erosion. The study shows that crop canopy cover, particularly in Pomelo (T_1), reduces runoff by enhancing water infiltration, while the control plot (T_5) had the highest runoff. These findings suggest that larger canopies reduce runoff and promote groundwater recharge. Future research could optimize crop selection and field layout to further improve water conservation and soil moisture retention, contributing to sustainable farming practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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