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Enhancing Yield and Water Productivity of Pre-bearing Mango Orchards through Intercropping

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The extended juvenile phase of fruit crops, characterized by the interval between planting and fruit production, often limits income generation for small and medium - scale farmers. To identify suitable intercrops for enhancing productivity and profitability during the pre - bearing stage of mango, a field experiment was conducted during 2019 - 2020 at Bhubaneswar, India. The study evaluated three intercropping systems in a drip - irrigated mango (cv. Amrapali) orchard: (i) two rows of papaya (cv. Red Lady), (ii) two paired rows of pineapple (cv. Queen), and (iii) a combination of one row of papaya and one paired row of pineapple. Intercrops were grown on both sides of mango plants with and without paddy straw mulch under a randomized block design. Soil volumetric water content gradually declined from April to June and from December to March. Intercropping treatments did not significantly influence the vegetative growth of mango or the intercrops. However, the mango - pineapple system with straw mulch produced the highest pineapple equivalent yield (17.48 - 18.89 t ha^{-1}), water productivity (21.11-21.47 kg ha^{-1} mm^{-1}), and energy output (56.53 GJ ha^{-1}). This treatment also generated the greatest economic returns, with net profits ranging from INR 1.40 to 3.85 lakh ha^{-1} and a benefit : cost ratio of 1.67 - 2.81. The findings suggest that pineapple - based intercropping combined with drip irrigation and straw mulching can substantially improve the productivity and profitability of young mango orchards, particularly in water - limited regions of eastern India.

(***Key words:*** *Benefit:cost ratio, Drip irrigation, Paddy straw mulch, Papaya, Pineapple*)

In India, mango is cultivated over an area of 2.33 million ha, producing about 20.93 million tonnes annually (MoA & FW, 2023). Eastern India is an important mango - growing region where trees generally require 4 - 5 years to begin bearing and nearly 10 years to attain full productive capacity after planting (Swain, 2014). This prolonged juvenile phase poses a significant challenge to orchard profitability, as farmers must invest in orchard establishment and maintenance without receiving returns during the initial years. Mango orchards planted at a spacing of 6 m × 6 m provide ample inter - row space during the early growth period, which can be utilized for cultivating short - duration, market - oriented, and location-specific intercrops (Jain *et al.,* 2006). Such systems enhance the utilization of land, water, nutrients, and other resources while generating additional income for growers. Intercrops also contribute to soil conservation by reducing erosion, suppressing weed growth, and improving soil health (Swain, 2016). Therefore, intercropping offers an effective strategy for increasing land productivity and economic returns compared with sole mango cultivation (Bhatnagar *et al.,* 2007). However, the success of an intercropping system largely depends on the selection of suitable companion crops. Hence, identifying appropriate intercrops for cultivation during the juvenile stage of mango orchards is essential for improving farm profitability and resource - use efficiency.

Intercropping in mango orchards has received considerable attention as a strategy to enhance land productivity and farm income during the juvenile phase of the crop. Rajput *et al.* (1989) recommended the cultivation of pulse crops as intercrops in young mango orchards to generate additional returns before the onset of fruiting. Singh *et al.* (2012) evaluated several leguminous intercrops, including cowpea, french bean, pigeon pea, soybean, lentil, chickpea, and black gram, and reported that the mango - cowpea system produced

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the highest mango yield, followed by the mango - lentil system, while sole mango cultivation resulted in the lowest yield. In the Eastern Ghat, high land zone of Odisha, Swain (2014) assessed different intercropping combinations involving ginger, turmeric, cowpea, tomato, french bean, ragi, niger, and upland rice. The study revealed that the mango - guava - cowpea system performed best in terms of vegetative growth and fruit yield, followed closely by the mango - guava - French bean system. Similar benefits of mango - based intercropping systems in improving productivity and resource utilization have also been documented by several researchers (Sarkar *et al.,* 2004; Ratha and Swain, 2006; Raut, 2006; Jain *et al.,* 2006; Tiwari and Baghel, 2014).

Although intercropping in mango orchards has been extensively investigated, previous studies have primarily focused on conventional intercrops such as pulses and vegetables grown under surface irrigation systems. Information on the integration of high - value fruit crops, particularly papaya and pineapple, as intercrops in drip - irrigated pre - bearing mango orchards remains limited. Moreover, the interactive effects of drip irrigation and mulching on crop productivity, soil moisture conservation, water productivity, and economic returns under the degraded land conditions of eastern India have not been adequately explored. In addition to crop yield and profitability, energy - use efficiency is an important indicator for assessing the sustainability of agricultural production systems. Mango - based intercropping under drip irrigation involves considerable energy inputs through irrigation, mulching, fertilizers, labour, and other crop management operations. Therefore, energy analysis is essential to evaluate the efficiency and sustainability of different management practices within these production systems. The present study was undertaken with the hypothesis that the cultivation of high-value, low water-requiring fruit crops between mango rows, combined with drip irrigation and rice - straw mulching, would enhance system productivity, water - use efficiency, and economic returns in pre - bearing mango orchards of eastern India. Accordingly, the objectives of the study were: (i) to evaluate the performance of papaya and pineapple as intercrops in drip - irrigated pre - bearing mango orchards; (ii) to assess the influence of mulching on crop yield, soil moisture conservation, and water productivity in mango - based intercropping systems; (iii) to determine the economic feasibility of drip - irrigated mango - based intercropping systems under degraded land conditions of eastern India; and (iv) to analyse the energy use efficiency and sustainability of different mango - based intercropping systems under varying management practices.

MATERIALS AND METHODS

Details of experimental site

A field experiment was conducted at the ICAR - Indian Institute of Water Management (IIWM), Bhubaneswar, India, to assess the growth and fruit yield performance of three - year - old pre - bearing mango trees intercropped with papaya, pineapple, and their combination under drip irrigation in degraded land conditions. The study was carried out over the period 2015 - 2020; however, the results presented in this paper pertain to the years 2018 - 2020.The experimental site is situated at 20.3148° N latitude and 85.8106° E longitude, at an altitude of 48 m above mean sea level. The region experiences a tropical hot sub - humid climate. The experimental soil was classified as sandy clay loam, with a bulk density of 1.55 g cm^{-3}, soil pH of 6.7, and electrical conductivity ($EC_{1:2}$) of 0.09 dS m^{-1}. Soil moisture characteristics determined using a pressure plate apparatus indicated a field capacity of 26% and a permanent wilting point of 10% on a volumetric basis. The soil was low in organic carbon, available nitrogen (N), and available phosphorus (P), while the available potassium (K) content was in the medium range. The site receives an average annual rainfall of approximately 1500 mm, of which more than 80% occurs during the southwest monsoon season (June - September).

Treatment details

The study evaluated three mango-based intercropping systems involving mango (*Mangifera* *indica* L.) cv. Amrapali as the main crop. The intercropping treatments comprised: (i) mango intercropped with two rows of papaya (*Carica papaya* L.) cv. Red Lady, (ii) mango intercropped with two paired rows of pineapple (*Ananas comosus* L.) cv. Queen, and (iii) mango intercropped with one row of papaya and one paired row of pineapple. The intercrops were established on both sides of the mango trees under mulched and non-mulched conditions. The experiment was laid out in a randomized block design (RBD) with three replications. Mango saplings were planted during the first week of July 2015 at a spacing of 6 m × 6 m between rows and plants. Papaya and pineapple were planted at spacings of 2.0 m × 2.0 m and 0.45 m × 0.60 m, respectively. A detailed description of the treatments is provided in Table 1. Rice straw mulch was applied annually during the first week of October at the rate of 7 kg plant^{-1} for mango, 4 kg plant^{-1} for papaya, and 1 kg plant^{-1} for pineapple, following the recommendations of the Government of Odisha (GoO, 2016). The mulch was applied in the respective crop basins to conserve soil moisture and improve the growing environment.

Fertilizer application and intercultural operations

All crops were managed according to the recommended agronomic practices for the region. For mango, each plant received 15 kg farmyard manure (FYM), 300 g nitrogen (N), 150 g phosphorus (P_2O_5), and 300 g potassium (K_2O) annually. The full quantity of FYM along with half of the recommended N, P_2O_5, and K_2O was applied during the monsoon season (June - July), while the remaining half of the fertilizers was applied after the monsoon in October. Pineapple plants were supplied with 12g N, 4g P_2O_5, and 12g K_2O per plant per year, in addition to FYM at the rate of 10 t ha^{-1}. Nitrogen was applied in six equal splits, commencing two months after planting and continuing up to twelve months after planting. The entire dose of phosphorus and half of the potassium were applied at planting, whereas the remaining potassium was applied six months later. Papaya received 20 kg FYM, 250g N, 250g P_2O_5, and 250g K_2O per plant per year. Fertilizers were applied in two equal splits, with the first application made at the onset of the monsoon and the second during October. Irrigation water was supplied through a drip irrigation system to both mango and intercrops based on their respective crop water requirements. Weed control and other intercultural operations were carried out as needed throughout the cropping period to ensure proper crop growth and development.

Table 1. *Treatment details of intercrops in mango*

Treatment	Detail	Treatment	Detail
T_1	Mango intercropped with papaya and pineapple	T_5	Mango intercropped with pineapple in combination with straw mulching
T_2	Mango intercropped with pineapple	T_6	Mango intercropped with papaya in combination with straw mulching
T_3	Mango intercropped with papaya	T_7	Sole mango in combination with straw mulching
T_4	Mango intercropped with papaya and pineapple in combination with straw mulching	T_8	Sole mango

Water application system and evaluating its hydraulic performance

Irrigation water was applied to all crops through a drip irrigation system. For mango and papaya, an online drip system equipped with 16 mm lateral pipes and emitters having a discharge rate of 4 L h^{-1} was used. In the case of pineapple, an inline drip system with 16 mm lateral pipes and emitters delivering 2.6 L h^{-1} was installed.The irrigation requirement of each crop was determined based on crop evapotranspiration (ETc). Irrigation scheduling was carried out by estimating ETc using the approach proposed by Doorenbos and Pruitt (1984), as expressed in the following equation:

$$ET_c = K_c \times K_p \times E_p \qquad ...(1)$$

where K_c is crop coefficient, K_p is pan coefficient and E_p is Class-A pan evaporation rate (mm day-1). The values of K_c used were 0.4-0.8, 0.3-0.5 and 0.4-1.2 for mango, pineapple and papaya crops, respectively (Doorenbos and Pruitt, 1984; Allen *et al.,* 1998). The values of K_p used were 0.7 during winter months (November - February) and 0.8 during summer months (March - June). The daily values of Ep recorded during the experimental period at meteorological observatory of the ICAR - IIWM, Bhubaneswar were used in this study.

The volume of applied irrigation water, Viw (L d^{-1}) was computed using following expression (Panigrahi *et al.,* 2011).

$$V_{iw} = [\{(K_c \times K_p \times E_p) - ER\} \times S \times WPF / E_i] \qquad ...(2)$$

where, ER is effective rainfall (mm); S is plant canopy area (m^2), WPF is wetting percentage factor (0.4) and E_i is irrigation efficiency under drip irrigation (DI; 90%). The plant canopy area was estimated as πr^2, where 'r' is the canopy radius of the plants measured using measuring tape. The values of WPF and E_i under DI were used from Keller and Bliesner (1990). For all crops, irrigation was applied daily through the drip irrigation system. The quantity of water delivered was regulated and monitored using control valves and water meters installed on the respective sub-main pipelines, ensuring accurate application of the required irrigation volume.

Monitoring soil water content

Soil moisture content was determined up to a depth of 60 cm using the gravimetric method. The measured gravimetric moisture values were converted to volumetric soil moisture content (VSMC) by multiplying them by the corresponding soil bulk density. In the mulched treatments, the irrigation water applied was reduced by 13% compared with the non-mulched treatments, based on the findings and recommendations of an earlier study (Kumar *et al.,* 2008).

Recording plant growth, yield parameters and energy use efficiency

Biometric parameters, including plant height, canopy diameter, and trunk girth, were recorded at three - month intervals for mango, papaya, and pineapple. Fruit yield of papaya and pineapple was determined by harvesting and weighing the total produce obtained from each treatment. To facilitate comparison among the different mango - based cropping systems, total system productivity was expressed as pineapple equivalent yield (PEY). The conversion was necessary because the market prices of the component crops differed considerably, with pineapple, papaya, and mango being valued at approximately INR 15, INR 30, and INR 50 per kg, respectively, in the local market. A comprehensive inventory of all inputs and outputs associated with each cropping system was prepared for energy analysis. Input and output energies were estimated using the respective energy coefficients presented in Table 2. Energy calculations were performed for each year of the study and the mean values across the experimental period were used for analysis. Energy contributions from natural sources such as solar radiation, rainfall and wind were not included in the energy budgeting. Energy use efficiency was computed as the ratio of total output energy to total input energy following the methodology described by Rautaray *et al.* (2020) and Satapathy *et al.* (2026).

Estimating water productivity and production economics

Water productivity was calculated by dividing the total crop yield by the total volume of water utilized, which included both irrigation water and effective rainfall received during the cropping period. The estimation considered the entire mango - based cropping system, including the contribution of mango and intercrops, following the approach described by Panigrahi *et al.* (2011). The economic performance of the different cropping systems under drip irrigation and mulching treatments was evaluated by estimating

Table 2. *Energy equivalents of all inputs and outputs used in the experiment*

S. No.	Input/output	Unit	Energy equivalents (MJ unit^{-1})	References
Inputs				
1	Human labour (male)	Man-hour	1.96	Meena *et al.* (2022)
2	Human labour (female)	Man-hour	1.57	
3	Machinery	kg	62.70	
4	Diesel	L	56.31	
5	Water	m^3	1.02	
6	Electricity	kWh	3.6	
7	Paddy straw	kg	13.4	Chaudhary *et al.* (2017)
Chemical fertilizer				
8	N	kg	60.60	Meena *et al.* (2022)
9	P_2O_5	kg	11.10	
10	K_2O	kg	6.70	
11	Herbicide	kg	254.45	
12	Insecticide	kg	184.63	
Outputs				
13	Pineapple	kg	1.90	Nazri and Pebrian (2017)
14	Mango	kg	1.90	Singh and Mittal (1992)
15	Papaya	kg	1.90	Singh and Mittal (1992)

gross cost of cultivation, gross returns, net returns, and benefit:cost ratio. These economic indicators were computed using the standard procedures outlined by Reddy and Ram (1996).

Statistical analysis

The biometric observations collected during the study were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for a randomized block design (RBD). Treatment means were compared using Duncan's Multiple Range Test (DMRT) following the procedure described by Gomez and Gomez (1984). The significance of treatment effects was evaluated through the F-test, and differences among treatment means were assessed using the least significant difference (LSD) at the 5% level of significance.

RESULTS AND DISCUSSION

Soil water dynamics

The mean soil moisture distribution across the 0-15 cm, 15-30 cm, and 30-60 cm soil layers under different crop treatments during the experimental period (Fig. 1). The mean volumetric soil water content (VSMC) in the 0-15 cm soil layer progressively decreased from April (23.66%) to June (21.83%) and from December (24.40%) to March (23.20%). Similarly, the mean VSMC in the 15-30 cm soil layer progressively decreased from April (23.12%) to June (21.35%) and from December (24.05%) to March (22.60%). However, in the 30-60 cm the mean volumetric soil water content decreased from December (23.35%) to March (22.05%) only. The progressive decrease in soil moisture content may be attributed to increased evaporative demand during these periods, which enhanced soil water loss

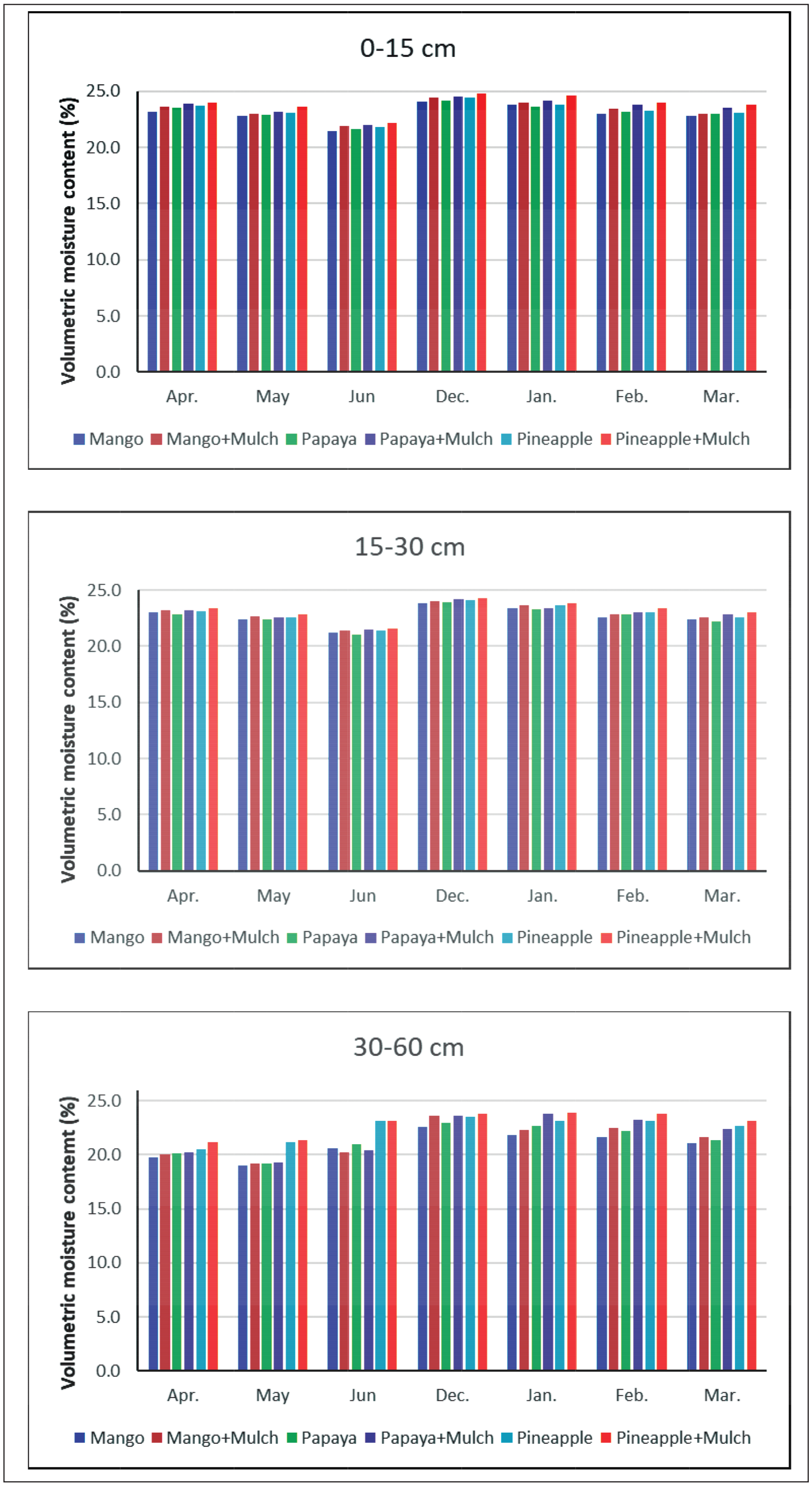

Fig 1. *Soil water dynamics in the 0-15 cm, 15-30 cm and 30-60 cm soil depth under different crops*

through evaporation and plant transpiration. Higher air temperature, greater solar radiation, and increased vapor pressure deficit during the summer and post-winter months accelerate evapotranspiration, thereby reducing the available soil moisture, particularly in the surface layers. The surface soil layers (0 - 15 cm and 15 - 30 cm) are more exposed to atmospheric conditions and root water uptake, resulting in faster depletion of moisture compared to deeper soil layers. In contrast, the 30 - 60 cm soil layer retained relatively higher moisture stability due to reduced direct evaporation losses and slower water extraction from deeper soil horizons. Many researchers have also observed that surface soil layers are more sensitive to seasonal fluctuations in evaporative demand and crop water uptake than subsurface layers (Lal and Shukla, 2004; Hillel, 2004).

Among the soil depths studied, the highest mean VSMC (23.38%) was observed in the 0 - 15 cm layer, followed by the 15 - 30 cm (22.88%) and 30 - 60 cm (21.80%) layers, indicating a decline in moisture content with increasing soil depth. Moreover, soil moisture content did not fall below the 50% allowable soil moisture depletion level (18%) in any crop during the study period. The relatively greater moisture content observed in the surface soil layer can be attributed to the drip irrigation system, which delivers water directly to the crop root zone through low-discharge emitters at frequent intervals, thereby maintaining higher moisture levels in the upper soil profile.This localized application reduces deep percolation losses and maintains a continuously wetted zone in the upper soil profile. Since most feeder roots are concentrated in the surface layers, water remains readily available in the 0 - 15 cm depth, resulting in comparatively higher moisture content. The gradual decline in moisture with increasing depth may be due to limited wetting front advancement and gravitational movement of water. Under drip irrigation, the wetted soil pattern generally forms a bulb-shaped zone, with maximum moisture concentration near the emitter. Regular application of irrigation water helps maintain soil moisture levels near field capacity, thereby minimizing moisture stress and enhancing the efficiency of water uptake by plant roots. This contributes to the maintenance of favourable soil moisture conditions throughout the crop growth period (Michael, 2007). In all the fruit crops, straw mulching enhanced soil moisture content up to 34 mm within 600 mm soil profile as compared to non-mulching, which is attributed to less soil water evaporation and lower soil temperature fluctuations under mulch conditions due to structural improvement (Swain, 2014; Lalruatsangi and Hazarika, 2018; Ma *et al.,* 2024). Across the root zone depths (0 - 15 cm, 15 - 30 cm, and 30 - 60 cm), soil water content was generally higher under pineapple (22.65 - 23.61%) than under papaya (21.57 - 23.39%) and mango (21.11 - 23.23%) in both mulched and non-mulched treatments. However, statistical analysis indicated that the differences in soil water content among the treatments were not significant ($p > 0.05$).

Vegetative growth parameters of fruit crops (mango, papaya and pineapple)

The vegetative growth parameters of mango, papaya, and pineapple during 2019 - 2020 are presented in Tables 3 - 5. In mango, plant height, canopy diameter, and trunk girth showed variations of 8%, 22%, and 15%, respectively, among the treatments. However, these differences were not statistically significant ($p > 0.05$). The presence of intercrops, with or without mulching, did not have any significant effect on the growth of mango plants. This may be due to the wider spacing of mango trees during the pre-bearing stage, which reduced competition for water, nutrients, and sunlight among the component crops (Swain, 2014). Similar findings were reported by Tiwari and Baghel (2014), who observed no significant effect of monocropping, companion cropping, or sequential cropping on the growth of mango. In papaya, plant height, canopy diameter, and number of fruits varied by 14%, 14%, and 11%, respectively, among the treatments. However, the differences were not significant ($p > 0.05$), indicating that mango-based intercropping did not adversely affect papaya growth and fruit production. For pineapple, shrub height and number of leaves varied by 10% and 16%, respectively, across the treatments. Similar to mango and papaya, these variations were not statistically significant ($p > 0.05$). The results suggest that the intercropping systems had little influence on

Table 3. *Vegetative growth parameter of mango*

Treatment	Plant height (m)	Canopy diameter (m)	Trunk girth (cm)
	2019-2020	2019-2020	2019-2020
T_1	3.43	3.20	38.38
T_2	3.50	3.50	41.45
T_3	3.49	3.10	38.90
T_4	3.47	3.30	38.58
T_5	3.59	3.60	43.67
T_6	3.55	3.20	42.30
T_7	3.69	3.90	44.23
T_8	3.66	3.80	44.18
Significance ($p<0.05$)	NS	NS	NS

Table 4. *Vegetative growth parameters of papaya*

Treatment	Plant height (m)	Canopy diameter (m)	Fruit number
	2019-2020	2019-2020	2019-2020
T_1	1.39	1.28	9
T_2	-	-	-
T_3	1.44	1.32	10
T_4	1.45	1.37	9
T_5	-	-	-
T_6	1.58	1.46	10
T_7	-	-	-
T_8	-	-	-
Significance ($p<0.05$)	NS	NS	NS

Table 5. *Vegetative growth parameters of pineapple*

Treatment	Shrub height (cm)	No. of leaves	No. of suckers/slips
	2019-2020	2019-2020	2019-2020
T_1	32.2	32	5
T_2	35.1	34	5
T_3	-	-	-
T_4	34.1	33	5
T_5	35.3	37	6
T_6	-	-	-
T_7	-	-	-
T_8	-	-	-
Significance ($p<0.05$)	NS	NS	NS

the vegetative growth of pineapple. Raut and Jain (2013) also reported no significant differences in the growth of intercrops grown in pomegranate orchards. The absence of significant effects in the present study may be attributed to adequate space availability and low competition for light, water, and nutrients during the pre-bearing stage of the mango orchard.

Water use, pineapple equivalent yield, and water productivity

The water use of mango, papaya, and pineapple during 2018 - 2019 was 636, 591, and 364 mm, respectively (Table 6). In 2019 - 2020, the corresponding values were 593, 415, and 237 mm. The differences in water use between the two years were mainly due to variations in rainfall, crop evapotranspiration, and crop growth. Although the crops showed greater growth during 2019 - 2020, lower rainfall and reduced evaporative demand resulted in lower water use compared with 2018 - 2019. Total water use in the mango-based intercropping systems ranged from 560 to 1591 mm during 2018 - 2019 and from 522 to 1245 mm during 2019 - 2020. Among the treatments, the mango-papaya-pineapple system without straw mulch used the highest amount of water, whereas sole mango with straw mulch recorded the lowest water use. Application of straw mulch reduced water use by up to 13% compared with the non-mulched treatments. This reduction was mainly due to lower evaporation losses from the soil surface. Straw mulch acted as a protective cover, reducing the direct effect of sunlight and wind on the soil. As a result, soil moisture was conserved for a longer period, improving water availability to crops and increasing water-use efficiency (Panigrahi *et al.,* 2010; Kumar *et al.,* 2015).

Table 6. *The amount of water used, pineapple equivalent yield and water productivity of mango-based intercropping*

Treatment	Water used (mm)		Pineapple equivalent yield (t ha^{-1})		Water productivity (kg ha^{-1} mm^{-1})	
	2018-2019	2019-2020	2018-2019	2019-2020	2018-2019	2019-2020
T_1	1591	1245	12.75b	23.37b	8.01cd	18.77d
T_2	1000	830	18.63a	28.56a	18.63b	34.41b
T_3	1227	1008	6.87c	18.17c	5.60d	18.03d
T_4	1400	1096	13.13b	24.12b	9.38c	22.01cd
T_5	880	735	18.89a	29.75a	21.47a	40.48a
T_6	1080	883	6.93c	19.37c	6.41d	21.93cd
T_7	560	522		13.17d	-	25.23c
T_8	636	593		12.16d	-	20.51cd

Note: Column means followed by identical letters indicate non-significant differences at the 5% probability level.

The productivity of the different mango-based cropping systems, expressed as pineapple equivalent yield (PEY), is presented in Table 6. The PEY ranged from 6.87 to 18.89 t ha^{-1} during 2018 - 2019 and from 13.17 to 29.75 t ha^{-1} during 2019 - 2020. The higher PEY in 2019–2020 was mainly due to the commencement of fruit production in mango trees. Among the treatments, the mango + pineapple system combined with straw mulch produced the highest PEY and was significantly superior to the other cropping systems. However, the difference between mulched and non-mulched mango-pineapple systems was not statistically significant. The lowest PEY was recorded in the mango + papaya system without mulch.The mango + pineapple system produced 88 -110% higher PEY than the mango-papaya-pineapple system and 172 - 221% higher PEY than the mango-papaya system. The higher productivity of mango-pineapple intercropping may be attributed to better utilization of available resources such as space, sunlight, water, and nutrients. Similar results have been reported by Tiwari and Baghel (2014), who observed higher productivity and economic returns in mango-based intercropping systems. Likewise, Swain (2014;

2016) and Ghosh *et al.* (2017) reported improvements in system productivity and resource-use efficiency through the inclusion of intercrops in fruit-based production systems.

Water productivity (WP) of the mango-based cropping systems varied from 5.60 to 21.47 kg ha^{-1} mm^{-1} during 2018 - 2019 and from 18.03 to 40.48 kg ha^{-1} mm^{-1} during 2019 - 2020 (Table 6). The onset of mango fruiting during 2019 - 2020 contributed to the substantial increase in WP. The highest WP was recorded in the mulched mango-pineapple system, whereas the lowest was observed in the non-mulched mango-papaya system. The WP values of mulched and non-mulched mango + papaya systems were statistically similar.The higher WP of the mulched mango + pineapple system was mainly due to its higher PEY combined with lower water use. Straw mulching improved WP by 17 - 23% compared with the non-mulched treatments. This improvement can be attributed to reduced evaporation losses, better soil moisture conservation, and increased water availability in the crop root zone. In addition, mulch helped regulate soil temperature, suppress weed growth, and reduce unproductive water losses. Consequently, a larger proportion of the applied water was utilized for crop production, resulting in higher water productivity (Mohanty *et al.,* 2002; Kumar *et al.,* 2015).

Energy use in mango-based intercropping

The total energy input was found by summing the energy inputs involved in human labour for different operations, along with application of manure (FYM), fertilizer, irrigation, mulching and plant protection. The results indicated that among the inputs used in cropping, the highest energy contribution was from fertilizer (41% - 43%), followed by mulch (29% - 30%), manure (9% - 11%), human labour (11% - 12%), irrigation (9% - 11%), and the least in plant protection (up to 1%). About 79% - 84% of total input energy is contributed by manures, straw mulch and fertilizers. Energy input varied considerably among the cropping systems (Fig. 2). The mango-papaya intercropping system required the highest energy input (57.43 GJ ha^{-1}), while the sole mango system recorded the lowest value (9.55 GJ ha^{-1}). The increased energy demand in the mango-papaya system can be largely attributed to the greater use of fertilizers and farmyard manure needed to support crop growth and productivity. The energy

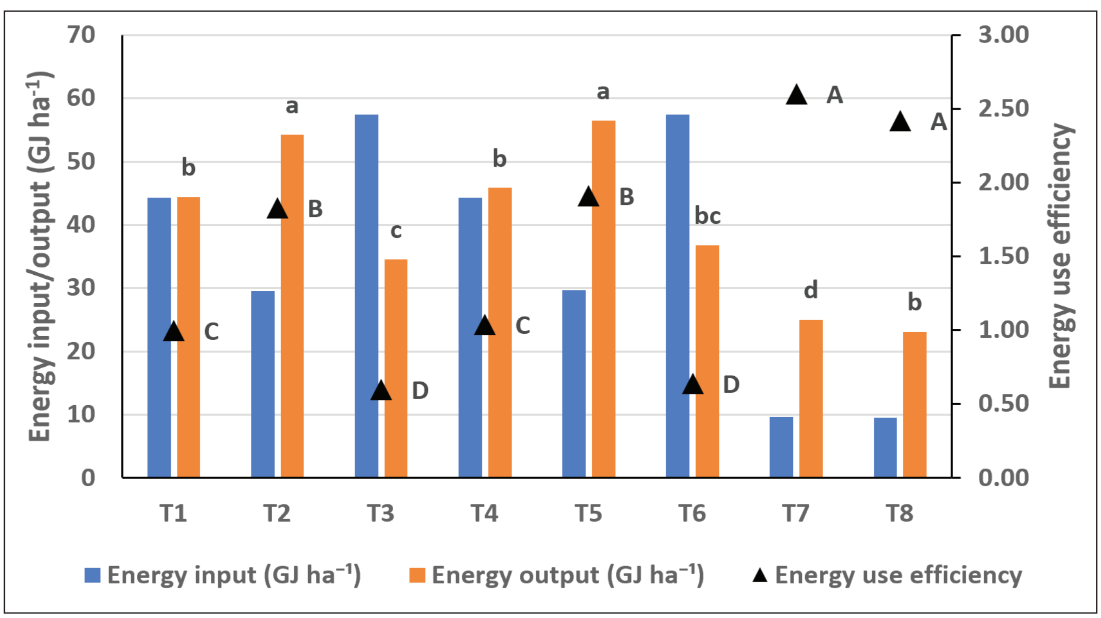

Fig 2. *Energy input, energy output, and energy use efficiency of mango-based cropping system. The small letters in the bar (energy output in GJ ha^{-1}) followed by the same small letters are not significantly (p>0.05) different. The capital letters in the marker (energy use efficiency) followed by the same capital letters are not significantly different (p>0.05)*

output followed a pattern similar to PEY under different systems. The mango-pineapple intercropping with mulch reported the significantly higher energy output (56.53 GJ ha^{-1}), and sole mango had the significantly lower energy output (23.11 GJ ha^{-1}). The energy output of mango-pineapple intercropping with and without mulch was statistically at par. Kishore *et al.* (2025) reported that the mango-pineapple intercropping system achieved greater energy use efficiency (1.32), energy productivity (0.65 kg MJ^{-1}), and energy profitability than other mango-based intercropping systems. The superior performance was attributed to the complementary use of available resources, including sunlight, soil moisture, nutrients, and land area, which enhanced overall system productivity without a proportional increase in energy inputs. Similarly, the energy output of sole mango with and without mulch was statistically comparable. Value of energy use efficiency more than 1 indicates that production system is gaining energy; otherwise, the system looses the energy (Satapathy *et al.,* 2026). The energy use efficiency (<1) of mango-papaya intercropping suggested to discontinue this practice.

Economics of mango-based intercropping

Although the mango-pineapple intercropping system with straw mulch involved a higher cultivation cost (INR 2,09,600 ha^{-1}), it recorded the maximum net return (INR 1,40,000 ha^{-1}) during the pre-bearing phase of the mango orchard (Table 7). This was primarily due to the higher economic returns generated from pineapple cultivation. Among the mulched intercropping systems evaluated during the pre-bearing period, the mango-pineapple system achieved the highest benefit-cost ratio (1.67), reflecting its greater economic viability compared to the other treatments. However, mango-papaya intercropping with/without mulch, wasn't found economically viable due to returns being less than the cost of production. Similar to the pre-bearing orchard, the highest gross return (INR 5,97,400 ha^{-1}) and net return (INR 3,84,600 ha^{-1}) were observed in mango-pineapple intercropping with mulch. All the intercropping systems without mulch had a B:C ratio ≥2.0. The mango alone without straw mulch had a B : C ratio of 1.99. The highest B : C ratio (2.81) was observed in mango-pineapple intercropping with mulch as compared to other intercropping. In earlier studies, the highest net returns were obtained in intercropping of mango+ginger (Rath and Swain, 2006; Raut and Jain, 2013), mosambi+groundnut (Ghosh and Pal, 2010), mango+guava+turmeric (Swain, 2014) and guava+banana (Ghosh *et al.,* 2017).

CONCLUSION

Among the intercropping options evaluated, namely papaya, pineapple, and a combination of papaya and pineapple, the mango - pineapple system performed the best. It recorded the highest pineapple equivalent yield and water productivity while using the least amount of water during both the pre-bearing

Table 7. *Economic performance of mango-based intercropping systems under drip irrigation and straw mulching during the pre-bearing and bearing stages of mango orchard.*

Treatment	Gross investment (INR ha^{-1})		Gross return (INR ha^{-1})		Net return (INR ha^{-1})		Benefit:cost ratio	
	Pre-bearing mango orchard	Bearing mango orchard	Pre-bearing mango orchard	Bearing mango orchard	Pre-bearing mango orchard	Bearing mango orchard	Pre-bearing mango orchard	Bearing mango orchard
T_1	208000	210400	224800	466600	16800	256200	1.08	2.22
T_2	208000	210600	342800	584600	134800	374000	1.65	2.78
T_3	150000	152500	106800	348600	-43200	196100	0.71	2.29
T_4	210700	213900	227400	482200	58400	268300	1.08	2.25
T_5	209600	212800	349600	597400	140000	384600	1.67	2.81
T_6	151600	154800	108600	354400	-43000	199600	0.72	2.29
T_7	118000	121200	-	241800	-118000	120600	-	2.00
T_8	116400	119600	-	238600	-116400	119000	-	1.99

and bearing stages of the mango orchard under drip irrigation with straw mulch. The mango-pineapple system also generated the highest net return (INR 3,84,600 ha^{-1}) and benefit:cost ratio (2.99) compared with the other intercropping systems. In addition, it achieved the highest energy output (56.53 GJ ha^{-1}) and higher energy use efficiency (1.91), indicating better utilization of energy inputs for crop production. Based on these results, intercropping pineapple in mango orchards under drip irrigation and straw mulch can be recommended as a profitable and water-efficient production system for the water-limited regions of eastern India. Further research should focus on identifying other suitable location-specific intercrops and assessing the long-term performance of the mango:pineapple system under different agro-climatic conditions across the country.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). *Crop Evapotranspiration : Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper No. 56. Food and Agriculture Organization (FAO) of the United Nations, Rome.

Bhatnagar, P., Kaul, M.K. and Singh, J. (2007). Effect of intercropping in kinnow based production system. *Indian Journal of Arid Horticulture* **2**: 15-17.

Choudhary, M., Rana, K.S., Bana, R.S., Ghasal, P.C., Choudhary, G.L., Jakhar, P. and Verma, R.K. (2017). Energy budgeting and carbon footprint of pearl millet-mustard cropping system under conventional and conservation agriculture in rainfed semiarid agro-ecosystem. *Energy* **141**: 1052-1058.

Doorenbos, J. and Pruitt, W.O. (1984). *Guidelines for Predicting Crop Water Requirements.* FAO Irrigation and Drainage Paper No. 24. Food and Agriculture Organization (FAO) of the United Nations, Rome.

Ghosh, S., Sarkar, S., Sau, S., Karmakar, S. and Brahmachari, K. (2017). Influence of guava based intercropping systems on soil health and productivity in alluvial soil of West Bengal, India. *International Journal of Current Microbiology and Applied Sciences* **6**(11): 241-251.

Ghosh, S.N. and Pal, P.P. (2010). Effect of intercropping on plant and soil of mosambi sweet orange orchard under rainfed conditions. *Indian Journal of Horticulture* **67**(2): 185-190.

Gomez, K.A. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research,* 2nd edition. Wiley.

GoO. (2016). *Odisha Agriculture Contingency Plan for District: Khurda 1.0.* Government of Odisha (GoO). Available at https://agriwelfare.gov.in

Hillel, D. (2004). *Introduction to Environmental Soil Physics.* Elsevier Academic Press, Amsterdam.

Jain, P.K., Raut, R.L. and Rajwade, V.B. (2006). Mango based intercropping under the watershed of Kymore plateau of Madhya Pradesh. *Indian Journal of Horticulture* **65**: 486-487.

Keller, J. and Bliesner, R.D. (1990). *Sprinkler and Trickle Irrigation,* Van Nostrand Reinhold, New York, 652 p.

Kishore, K., Sangeetha, G., Rupa, T., Ganeshmurthy, A.N., Samant, D., Acharya, G.C. and Srninivas,

P. (2025). Assessment of mango-based intercropping systems for productivity, resource use efficiency and environmental sustainability in tropical region of India. *Next Sustainability* **5**: 100121.

Kumar, D., Pandey, V. and Nath, V. (2008). Effect of organic mulching and irrigation through drip on growth and yield of 'Lat Sundari' mango (*Mangifera indica*) in eastern India. *Indian Journal of Agricultural Sciences* **78**(5): 385-388.

Kumar, V., Bhat, A.K., Sharma, V., Gupta, N., Sohan, P. and Singh, V.B. (2015). Effects of different mulches on soil moisture, growth and yield of Eureka lemon under rainfed condition. *Indian Journal of Dryland Agricultural Research and Development* **30**(1): 83-88.

Lalruatsangi, E. and Hazarika, B.N. (2018). Effect of various mulching materials on crop production and soil health in acid lime. *International Journal of Agriculture Environment and Biotechnology* **11**(2): 311-317.

Lal, R. and Shukla, M.K. (2004). *Principles of Soil Physics.* Academic Press, New York.

Ma, J., Chang, L., Li, Y., Lan, X., Ji, W., Zhang, J., Han, F., Cheng, H., Chai, Y. and Chai, S. (2024). Straw strip mulch improves soil moisture similar to plastic film mulch but with a higher net income. *Agriculture, Ecosystems & Environment* **362**:108855.

Meena, O.P., Sammauria, R., Gupta, A.K., Gupta, K.C., Behera, B., Saxena, R., Yadav, M.R., Singh, P., Meena, R.K., Raza, M.B., Anil, A.S. and Lal, M.K. (2022). Energy-carbon footprint vis-à-vis system productivity and profitability of diversified crop rotations in semi-arid plains of north-west India. *Journal of Soil Science and Plant Nutrition* **22**: 2026-2041.

Michael, A.M. (2007). *Irrigation: Theory and Practice*. Vikas Publishing House Pvt. Ltd., New Delhi, 772 p.

MoA & FW. (2023). *Agricultural Statistics at a Glance - 2023.* Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare (MoA & FW), Government of India, New Delhi, India.

Mohanty, S., Sonkar, R.K. and Marathe, R.A. (2002). Effect of mulching on Nagpur mandarin cultivation in drought prone region of central India. *Indian Journal of Soil Conservation* **30**(3): 286-289.

Nazri, A.M. and Pebrian, D.E. (2017). Analysis of energy consumption in pineapple cultivation in Malaysia: A case study. *Pertanika Journal of Science and Technology* **25**(1): 17-28.

Panigrahi, P., Srivastava, A.K. and Huchche, A.D. (2010). Optimizing growth, yield and water use efficiency (WUE) in Nagpur mandarin under drip irrigation and plastic mulch. *Indian Journal of Soil Conservation* **38**(1): 42-45.

Panigrahi, P. and Srivastava, A.K. (2011). Integrated use of water and nutrients through drip irrigation in Nagpur mandarin. *Journal of Agricultural Engineering* **48**(3): 44-51.

Rajput, M.S., Shrivastava, K.C. and Shukla, V. (1989). Intercropping in young mango orchard. *Acta Horticulturae* **231**: 312-315.

Ratha, S. and Swain, S.C. (2006). Performance of intercrops in mango orchard in Eastern Ghat High Land Zone of Orissa. *Indian Journal of Dryland Agricultural Research and Development* **21**: 12-15.

Raut, R.L. (2006). Performance of various intercrops in relation to land equivalent ratio (LER) and their influence on yield attributes and yield of mango. *Journal of Soils and Crops* **16**: 295-299.

Raut, R.L. and Jain, P.K. (2013). Intercropping systems in mango orchard for rainfed area of central India. *International Journal of Horticulture* **3**(15): 87-90.

Rautaray, S.K., Pradhan, S., Mohanty, S., Dubey, R., Raychaudhuri, S., Mohanty, R.K., Mishra, A. and Ambast, S.K. (2020). Energy efficiency, productivity and profitability of rice farming using sesbania as green manure-cum-cover crop. *Nutrient Cycling in Agroecosystems* **116**: 83-101.

Reddy, S.S. and Ram, P.R. (1996). *Agricultural Finance and Management*, 2nd edition. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, p. 268.

Sarkar, S.K., Gautam, B., Seethambram, Y. and Vijaya, N. (2004). Effect of intercropping sequence with vegetables in young mango orchard under Decan plateau. *Indian Journal of Horticulture* **61**: 125-127.

Satapathy, B.S., Pradhan, S.,Panda, D.K., Behera, B., Nayak, A.K., Rautaray, S.K., Mishra, S.K. and Sarangi, A. (2026). Optimizing land and water management for improvingquinoa yield, profitability and resource use efficiency in an acid Inceptisol of Eastern India. *The Journal of Agricultural Science* **164** (e21), 1-14. https://doi.org/10.1017/S0021859626100598

Singh. S.R., Banik, B.C. and Yumnam, S.S. (2012). Effect of different intercrops on yield and quality of mango production in new alluvial zone of West Bengal. *The Asian Journal of Horticulture* **7**(2): 582-585.

Singh, S. and Mittal, J.P. (1992) *Energy in Production Agriculture.* Mittal Publications, New Delhi.

Tiwari, R. and Baghel, B.S. (2014). Effect of intercropping on plant and soil of Dashehari mango orchard under low productive environments. *The Asian Journal of Horticulture* **9**(2): 439-442.