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Effect of Organic Manures on Growth, Yield and Quality of Papaya (*Carica papaya* L.) cv. Taiwan Red Lady-786

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Abstract: Papaya (*Carica papaya* L.) is a heavy nutrient-exhaustive crop that needs a continuous and balanced supply of nutrients to achieve optimal growth, yield and fruit quality. But overreliance on chemical fertilizers has a negative impact on environmental sustainability, soil health and long term productivity, highlighting the importance of adopting sustainable organic nutrient management practices. This study was conducted to assess the impact of various combinations of organic manures on plant growth, yield and quality of papaya. This study was conducted with using a Randomized Block Design (RBD), evaluating various organic treatments against the control (T0). The statistical results revealed that the significant differences among the treatments on vegetative, yield and biochemical parameters. T5 shown better performance with regard to the following traits: max. plant height (112.79 cm at 120 DAP), number of leaves, stem girth, number of fruits per plant (28.93), fruit yield per plant (42.46 kg) and yield per hectare (126.85 t ha^{-1}). The papaya fruit quality parameters were also improved on treatment T5, with significant increase in total sugars (9.1%), reducing sugars (6.80%), total soluble solids (11.92 %), lycopene content and fruit firmness (4.7 kg cm^{-2}) and a longer shelf life (7.6 days). The three multivariate statistical analysis methods all showed T5 as the most effective treatment, suggesting equal effectiveness on productivity and fruit quality parameters. This is perhaps because of the superior soil fertility, nutrient release, microbial activity and physiological efficiency under integrated organic nutrient management with T5. As per the results of the study, it is recommended for organic manures in the right combinations can be used as a sustainable and environmentally friendly approach to enhance the productivity, quality and sustainability of papaya crop.

1. Introduction

Papaya crop is most valuable and nutritious fruit crop in tropical and sub-tropical climatic countries because of its nutritional, medicinal and economic importance. It is part of the family Caricaceae [1] and is widely cultivated in India owing to its short maturity period, prolific fruiting and early crop. The papaya fruits can be used in fresh markets, besides being suitable for the processing industry due to their nutritional content (high in vitamin A and vitamin C, minerals, carbohydrates, carotenoids, antioxidants, and papain enzyme) [1-3]. India is the major producing country of papaya in the world and it is also one of the most important crops to boost the income of small and marginal farmers [1,4]. According to [5,6] papaya is a heavy feeder crop and needs to be supplied with nutrients continuously throughout its growth and fruiting period for better productivity and fruit quality. Traditionally, nutrients are supplied in the form of chemical fertilizer, but overuse and repeated use of inorganic fertilizers have had a negative impact on soil fertility, microbial activity, environmental quality and the sustainability of production systems. The constant use of chemical fertilizers may also cause soil compaction, nutrient imbalance, contamination of the groundwater and deterioration of the quality of the fruit [6,7]. With this background, there is growing demand to switch to sustainable nutrient management using organic manures and biofertilizers [8,9].

Although the importance of organic agriculture is increasing, there is still a lot of information about the comparative impact on plant growth, yield and quality attributes of papaya cultivated with various forms of organic manure under field conditions. Hence, the present study "Effect of Different Organic Manures on Growth, Yield and Quality of Papaya" was carried out to assess the effect of different combination of organic manures on vegetative growth, fruit yield and quality attributes of papaya and also to recommend the appropriate organic nutrient management practices for successful papaya production.

2. Material and methods

2.1. Experiment location and Planting Material

The present Experiment was conducted at Krishi vigyan Kendra, Tuniki, Kowdipally Mandal, Medak District, Telangana, India, during the experimental period under tropical climatic conditions. Healthy and uniform seedlings of Taiwan Red Lady-786 were used for planting. The trial was conducted in a Randomized Block Design (RBD) featuring nine treatments with three replications.

2.2. Design of Experiment and Treatments

The experiment consists of nine nutrient management treatments involving various combinations of organic manures, chemical fertilizer and untreated control. Each treatment was replicated three times with five plants per treatment, comprising a total of 135 plants. The spacing adopted was 1.8 m × 1.8 m under square system of planting. The treatment details are as follows T0: Untreated control, T1: Recommended dose of chemical fertilizers (RDF), T2:Farmyard manure (FYM) equivalent to the 100% recommended dose of nitrogen (RDN), T3: Vermicompost (VC) equivalent to 100% RDN, T4: Poultry manure (PM) equivalent to 100% RDN, T5: FYM equivalent to 50% RDN + VC equivalent to the 50% RDN, T6: FYM equivalent to the 50% RDN + PM equivalent to 50% RDN, T7: FYM equivalent to the 75% RDN + VC equivalent to the 25% RDN, T8: FYM equivalent to 75% RDN + PM equivalent to 25% RDN.

2.3. Nutrient status of soil and Organic manures

Before the start of the trial, a soil sample of the experimental field and organic manure samples are collected and analysed. The nutrient status, organic carbon and pH details are given in Table1.

Table 1: Nutrient composition of Soil, FYM, Vermi compost and Desi poultry manure samples.

Sample	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	pH	OC (%)
Soil	136.95	28.63	156.26	7.62	0.33
FYM	0.56	0.16	0.48	8.01	13.71
VC	1.59	0.73	0.98	7.31	6.83
PM	1.96	2.42	2.36	6.98	12.45

2.4. Application of Organic Manures

The organic manures like FYM, Vermicompost, and poultry manure, were used to apply based on the nitrogen nutrient content in the sample, equivalent to the recommended dose of nitrogen for each plant per year. The application rates were: Recommended Nitrogen fertilizer (250 g), 100% equivalent FYM (44.64 kg), 100% equivalent vermicompost (15.72 kg), and 100% equivalent poultry manure (12.75 kg) per plant/year. This quantity was calculated based on treatment composition and applied in 6 split doses with two months intervals at the basal portion of the plant by making a 15 cm deep trench around the plant at the root zone, covering with soil after application.

2.5. Growth Parameters

Observations on vegetative growth were recorded at 30, 60, 90 and 120 days after planting (DAP). The parameters included number of leaves per plant, stem girth (cm) and plant height (cm).

2.6. Yield Parameters

Yield contributing characters and yield were recorded at harvest. The observations included average fruit weight (g), number of fruits per plant, fruit radial diameter, fruit polar diameter (cm), (cm), specific gravity (w/v), fruit yield per plant (kg), and yield per hectare (t ha^{-1}).

2.7. Quality Parameters

Fruit quality parameters were analyzed using standard laboratory procedures. The parameters studied included pulp thickness (cm), fruit firmness (kg cm^{-2}), carotene content (µg mL^{-1}), lycopene content (mg 100 g^{-1}), total sugars (%), reducing sugars (%), non-reducing sugars (%), total soluble solids (TSS,%) and shelf life under room temperature conditions.

2.8. Statistical study

Data of the experiment obtained from various observations are exposed to analysis of variance (ANOVA) appropriate for Randomized Block Design (RBD). Statistical analysis was performed using SAS software, and the treatment means were analyzed at 5% level of significance ($p < 0.05$).

3. Results and Discussion

3.1. Effect of Organic Manures on Growth, Yield and Physical Parameters of Papaya (*Carica papaya* L.)

Various organic treatments exerted a significant impact on papaya growth, yield and physical parameters (Table 2). The vegetative performance of T5 was consistently superior in plant height (42.40 cm, 69.67 cm, 88.20 cm and 112.79 cm at all growth stages of 30, 60, 90 and 120 DAP, respectively), stem girth, number of leaves per plant, number of fruits per plant (28.93), specific gravity and fruit yield per plant (42.46 Kg/tree) and yield per hectare (126.85 t ha^{-1}) while the control treatment (T0) recorded the lowest value for most parameters. Higher growth and yield for T5 may be due to balanced nutrient supply, increased microbial activity, increased root growth, increased soil aeration and moisture holding capacity, and the continuous mineralization of nutrients from organic sources which culminated in an increased rate of photosynthesis, efficient assimilate translocation and higher reproductive efficiency. The integrated nutrient supply also resulted in fruit size improvement as the nutrient supply in T5 resulted in the maximum radial diameter of the fruit and the maximum polar diameter was obtained in T7. The highest individual fruit weight was however recorded for T3 at 1.59 kg, this suggest that although fewer fruits were produced under T3 it was able to convert assimilates into individual fruit with a greater efficiency, thus producing larger fruit size. In contrast, T5 yielded comparatively smaller sized fruits with higher fruit number and better vegetative growth resulting in higher yield. Mishra et al. [9] and other earlier workers [10] reported similar results for integrated organic nutrient management for papaya that brought about improved growth and yield.

The superiority of treatment T5 could be attributed to the combined effect of FYM and vermicompost providing immediate nutrient supply as well as slow release when the crop grew throughout its period. Vermicompost provides readily available nutrients, growth promoting substances, humic acid and beneficial microorganisms and FYM, enhances soil structure, cation exchange capacity and long-term buffering capacity. This mix will improve the efficiency of nitrogen mineralization, phosphorus solubilization and potassium availability, which will help papaya plants better synthesize chlorophyll and increase their photosynthetic efficiency and better source–sink relationship. With integrated organic nutrition, it also increases the microbial activity which in turn increases the production of Phytohormones like Auxins and Gibberellins which stimulates cell division, root growth and fruit development. The higher fruit weight of T3 compared to T5 could be attributed to lesser fruit load and competition between developing fruits, which could allow the production of more carbohydrates and metabolites by individual fruits, while in T5, the fruit had allocated assimilates to yield maximum number of fruits. Recent investigations into the integrated organic nutrient management in papaya and other tropical fruit crops have also shown that application of FYM, vermicompost and bio-inputs could improve the nutrient use efficiency, soil biological activity, fruit quality and sustainable yield, as it would provide continuous nutrient supply and maintain soil health in the rhizosphere. The results indicate that integrated with organic manure application not only increased productivity, but it also contributed to soil fertility and sustainability of papaya cultivation.

3.2 Effect of Organic Manures on Quality parameters of Papaya (*Carica papaya* L.) Hyb. Taiwan Red lady -786

All fruit quality parameters of papaya were greatly affected by organic manure treatments. The best quality attributes were seen with the T5 treatment with the maximum total sugars (9.1%), reducing sugars (6.80%), lycopene content (3120 mg/100 g), TSS (11.92%), fruit firmness (4.7 kg cm^{-2}), longest shelf life (7.6 days), while the control treatment (T0) exhibited the lowest values for most of the quality parameters. The contents of non-reducing sugars were higher in T1, T2, T6 and T7 while the maximum content of beta carotene was observed in T2 (1860 mg/100 g) (Fig 1) Likewise, maximum pulp thickness (2.98 cm) was obtained with T7, which also had relatively high TSS, firmness and shelf life. These increases in fruit quality with integrated organic manure treatments could be explained by increased nutrient uptake, increased photosynthetic efficiency, increased carbohydrate synthesis and better assimilate translocations from source to sink. Under organic nutrition, the fruits also had an improved sweetness, colour development, pulp quality and storage life due to the enhanced microbial activity and nutrient mineralization, leading to biosynthesis of carotenoids, sugars and soluble metabolites. Higher calcium availability and structural integrity of fruit tissues with organic manure application also played a role in enhancing fruit firmness and post harvest deterioration delay. The same quality parameters improvement of papaya with integrated organic nutrient management was also reported by Mishra et al. [9] and Vishwakarma [10] other recent studies related to tropical fruit crops.

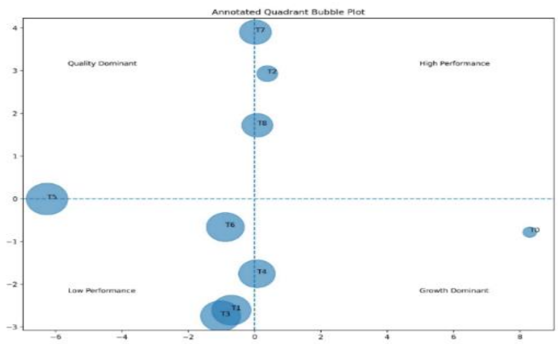

Fig. 1. Annotated quadrant bubble plot showing comparative performance of organic manure treatments based on growth, fruit yield and bio chemical parameters of papaya (*Carica papaya* L.).

Physiologically, enhanced performance of T5 can be explained by the synergistic nutrient release pattern in the combination of FYM and vermicompost, where the first one provided readily available macro- and micronutrients, enzymes, beneficial microbes and growth promoting substances, and the latter one provided gradual nutrient release, increase in soil organic carbon, moisture holding capacity and cation exchange capacity. This integrated nutrient dynamics ensured a continuous nutrient uptake throughout all the phases of fruit development and ripening, which improved the metabolism of carbohydrates, the biosynthesis and accumulation of carotenoids in the fruit and total soluble solid content in the fruit. Higher microbial activity in the rhizosphere might also have triggered the increased enzyme activities responsible for the conversion of sugars and synthesis of pigments, which led to higher total sugars, reducing sugars, lycopene and TSS in T5. The correlations between the treatmnet and characterstisc and overall performance of the factors on the charactersisc are shown in Fig 2 and Fig 3.The heat map illustrates higher values in red, whereas blue represents lower values of the studied traits.

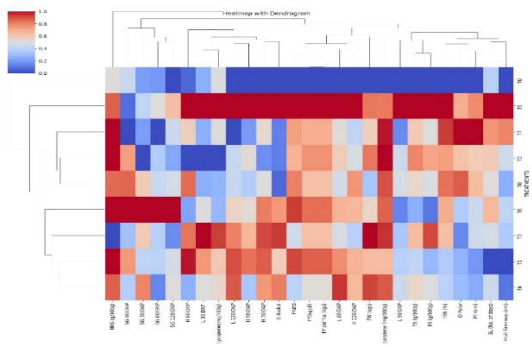

Fig. 2. Heatmap clustering of organic manure treatments based on growth, fruit yield and biochemical parameters of papaya (*Carica papaya* L.).

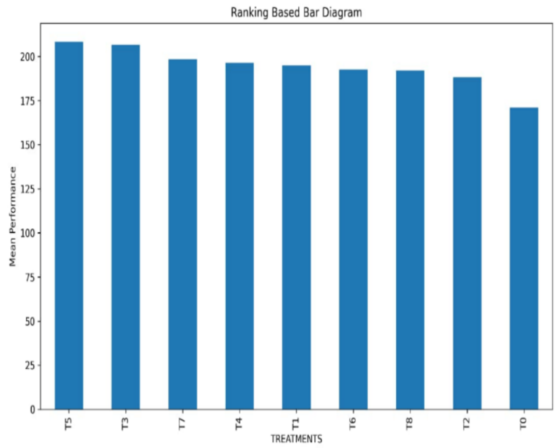

Fig. 3. Ranking-based bar diagram showing overall performance scores of organic manure treatments for growth, fruit yield and biochemical parameters of papaya (*Carica papaya* L.).

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Table 2: Impact of organic manures on growth and yield parameters

	No. of Leaves				Plant height (cm)				Stem girth (cm)				Diameter		Yield			
Treatment	**30 DAP**	**60 DAP**	**90 DAP**	**120 DAP**	**30 DAP**	**60 DAP**	**90 DAP**	**120 DAP**	**30 DAP**	**60 DAP**	**90 DAP**	**120 DAP**	**Polar (cm)**	**Radial (cm)**	**No. of Fruits**	**Individual fruit weight (Kgs)**	**Fruit yield per plant (Kg/pl)**	**Fruit yield per ha (Kgs)**
T0	16 ^{cd}	16.13 ^{c}	20.53 ^{b}	21.93 ^{b}	37.59 ^{c}	59.80 ^{bc}	74.17 ^{d}	90.89 ^{c}	0.9 ^{e}	9.56 ^{b}	14.97^{abc}	18.99 ^{d}	30.5 ^{d}	20.6 ^{c}	13.00 ^{d}	1.07 ^{c}	13.98 ^{f}	41.77 ^{f}
T1	18 ^{ab}	20 ^{b}	22.4 ^{b}	25.07 ^{a}	41.80 ^{a}	69.47 ^{a}	85.95 ^{ab}	105.79 ^{ab}	1 ^{d}	10.9 ^{b}	16.13^{ab}	21.77 ^{bc}	32.5 ^{cd}	22.5 ^{abc}	27.67 ^{a}	1.41 ^{ab}	38.83 ^{ab}	116.01 ^{ab}
T2	15 ^{d}	19.07 ^{b}	22.73 ^{b}	23.4 ^{ab}	38.37 ^{bc}	59.13 ^{c}	81.43 ^{abcd}	101.3	0.8 ^{f}	10.74 ^{b}	16.08^{ab}	20.34 ^{cd}	35.3 ^{abc}	21 ^{bc}	23.80 ^{abc}	1.50 ^{ab}	35.85 ^{bcd}	107.12 ^{bcd}
T3	19 ^{a}	18.53 ^{b}	22.2 ^{b}	24.73 ^{ab}	42.00 ^{a}	67.87 ^{ab}	83.57 ^{abc}	99.27 ^{bc}	1.1 ^{c}	10.8 ^{b}	14.54^{abc}	19.91 ^{d}	31.6 ^{d}	**23.6 ^{a}**	20.27 ^{bc}	**1.59 ^{a}**	32.18 ^{de}	96.15 ^{de}
T4	17 ^{bc}	20.87 ^{a}	22.73 ^{b}	25.00 ^{a}	41.20 ^{ab}	61.83 ^{abc}	78.83 ^{bcd}	105.29 ^{ab}	1.2 ^{b}	9.28 ^{b}	14.73^{abc}	21.99 ^{bc}	32.7 ^{bcd}	23.2 ^{a}	19.20 ^{c}	1.55 ^{ab}	28.87 ^{e}	86.25 ^{e}
T5	**19 ^{a}**	**21.13 ^{a}**	**25.47 ^{a}**	**25.4 ^{a}**	**42.40 ^{a}**	**69.67 ^{a}**	**88.20 ^{a}**	**112.79 ^{a}**	1 ^{d}	11.7 ^{b}	13.67^{bc}	22.83 ^{b}	35.8 ^{ab}	**23.8 ^{a}**	**28.93 ^{a}**	1.50 ^{ab}	**42.46 ^{a}**	**126.85 ^{a}**
T6	17 ^{bc}	19.53 ^{b}	21.20 ^{b}	23.87 ^{ab}	41.50 ^{ab}	61.47 ^{abc}	81.53 ^{abcd}	105.59 ^{ab}	**1.3 ^{a}**	**14.89 ^{a}**	**17.05^{a}**	**24.93 ^{a}**	33.2 ^{bcd}	23 ^{ab}	27.93 ^{a}	1.36 ^{ab}	38.04 ^{abc}	113.65 ^{abc}
T7	16 ^{cd}	18.67 ^{b}	21.27 ^{b}	21.93 ^{b}	40.20 ^{abc}	65.27 ^{abc}	76.86 ^{cd}	99.75 ^{bc}	0.9 ^{e}	8.38 ^{b}	13.38^{c}	21.57 ^{bc}	**38.1 ^{a}**	21 ^{bc}	24.67 ^{ab}	1.37 ^{ab}	33.74 ^{cd}	100.81 ^{cd}
T8	16 ^{cd}	18.47 ^{b}	22.87 ^{b}	23.4 ^{ab}	40.00 ^{abc}	68.07 ^{a}	79.26 ^{bcd}	107.57 ^{ab}	1.1 ^{c}	11.2 ^{b}	16.54^{a}	21.73 ^{bc}	37.2 ^{a}	20.8	25.87 ^{a}	1.24 ^{bc}	32.12 ^{de}	95.96 ^{de}
CD(5%)=	1.46	1.58	2.44	2.56	2.95	7.35	7.53	10.91	0.09	2.63	2.26		2.93	1.91	4.83	0.28	4.45	13.31
S.EM=	0.49	0.53	0.81	0.85	0.98	2.45	2.51	3.64	0.03	0.88	0.75	0.5	0.98	0.64	1.61	0.09	1.49	4.44
SE.d=	0.69	0.75	1.15	1.21	1.39	3.47	3.55	5.15	0.04	1.24	1.07	0.71	1.38	0.90	2.28	0.13	2.10	6.28
CV=	4.98	4.77	6.29	6.19	4.20	6.56	5.70	6.11	5.09	8.30	8.58	4.03	4.99	4.97	11.88	11.38	7.82	7.82

a = Top tier. This value is in the highest group and is significantly higher than any value that doesn't have an a ; **ab** = Bridge value. It's not different from the a group, and it's also not different from the b group. It connects them; **abc** = Big overlap. Not different from a means, not different from b means, and not different from c means. Usually happens when you have high variability.**bc** = Middle-lower bridge. Not different from the b group and not different from the c group, but IS different from the pure a group. **cd** = Lower bridge. Not different from c and not different from d, but different from a and b; **bcd** = Wide overlap in the middle-to-low range. Not different from b, c, or d groups, but different from a; **abcd** = Everything overlaps. This mean is not statistically different from any other mean in the set. This happens with really noisy data or small sample sizes; **e=** Bottom tier. If it's just e, it's significantly lower than any mean that doesn't have an e.

fruits. While T2 and T7 had higher levels of beta carotene and pulp thickness, respectively, overall fruit quality was better in T5 with balanced nutrient availability and better metabolic efficiency. The increased firmness and shelf life in T5 can also be linked to increased calcium mediated cell wall stabilisation and decreased respiration rate under balanced organic nutrition. Recent studies on organic nutrient management for papaya and other fruit crops have also shown that the use of combined application of FYM and vermicompost has positive effects on soil biological activity, nutrient use efficiency, accumulation of antioxidants, post harvest quality and storage behaviour of fruit which helps to support sustainable production with enhanced nutrient quality

4. Conclusions

The results demonstrated that the significant differences between the treatments for the characteristics such as morphological, yield and biochemical parameters. Findings revealed that the positive outcome from the various organic manure combinations on papaya performance. In most of the measured physiological parameters, the treatment T5 showed the highest values of maximum fruit production, the quality attributes, accumulation of sugars, TSS, lycopene content, and overall productivity, showing its great physiological efficiency and balanced nutrient use, while the control treatment (T0) recorded the lowest values for almost all of the evaluated traits. Superscript letter comparisons also revealed that T1, T2, T5 and T6 were often statistically equal for multiple parameters, indicating similar positive responses when testing integrated mixes of organic nutrients. The quadrant bubble plot with annotation highlighted the high-performance quadrant for T5, T1 and T6 as they showed significant improvement in both yield and quality traits, whereas T2, T7 and T8 were grouped in a quadrant dominated by quality traits as they had greater impact on biochemical parameters than yield traits. However, T0 was definitely in the low performance quadrant due to lack of growth, yield and quality responses. The same applied with ranking based bar diagram revealed that T5 was the top ranked treatment and followed by T1 and T6, which showed the cumulative superiority of these treatments in various agronomic and biochemical traits. These results were also confirmed by heatmap with dendrogram analysis, which grouped T5 into a superior cluster with high positive correlations between yield, sugars, TSS, lycopene content and firmness of fruit, suggesting that all these traits are physiologically and metabolically correlated. The independent low-performance cluster of T0 further highlighted the need for integrated nutrient management in papaya production. The graphical interpretations of these indicate strong positive correlation between growth, yield and biochemical traits in integrated organic manure treatments especially in T5 which shows better nutrient release dynamics, microbial activity, assimilate partitioning and better metabolic performance.

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