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Sustainable Yield Increase in Castor (*Ricinus communis* L.) Cultivation Under Rainfed Condition

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Castor is an important oilseed crop growing under rainfed condition all over the world. The beneficial effect of integrated use of mineral fertilizers, organic manure along with bioinoculants on soil quality and crop productivity of castor crop and its potential in rainfed ecosystem was studied through a field experiment at Tapioca and Castor Research Station, TNAU Yethapur during *Kharif* (2013-14). The results of the present study indicated that the application of recommended dose of fertilizers (RDF) 45:15:15 kg NPK ha^{-1} and enriched farmyard manure (EFM) @ 750 kg ha^{-1} along with *Azospirillum* and *Phosphobacteria* (biofertilizers) had recorded the highest seed yield (1785 kg ha^{-1}) and oil content (48.5%). In all the enriched organic (enriched poultry manure, enriched vermicompost, enriched pressmud compost, enriched coirpith compost) amended treatments also significant increase in yield was observed. Among various treatments, compared to the control, the RDF with EFM had found to impart significant changes in the soil EC (0.43 dS m^{-1}) and macronutrients also improved to a mean of 35, 6.71, 19 kg ha^{-1} of N, P and K respectively. Hence, the combined use of organic, chemical and biological sources of fertilizers in appropriate proportions will ascertain the balanced nutrition to the crop and sustain the productivity.

Key words : Castor, INM, Yield, Oil content, Soil nutritional status.

Castor (*Ricinus communis* L.) is an important oilseed crop in India, having utilitarian value in industry, pharmaceutical and agricultural sectors. India is the largest producer of castor in the world and meets out 90% of the global castor oil requirement. Globally India shares 53 % of the area and contribute about 70 % of the production with a productivity average of 1392 kg ha^{-1} surpassing China and Brazil. Hydroxylated ricinoleic acid was extracted from castor and annually, India earns 703.81 million dollars by exporting castor oil (Dewan, 2015).

In Tamil Nadu the area under which castor cultivation is 15,000 ha with an average productivity of 800 kg ha^{-1}. Compared to national average, Tamil Nadu experiences low productivity, mainly due to its cultivation in the marginal land, under rainfed condition in nutrient depleted soils. Hence adoption of proper nutrient management practice is mandatory. Although soil is regarded as store house of nutrients, during the course of crop cultivation constant removal of nutrients take place. In order to meet out the optimal nutrient requirements of crops on a sustainable basis, combined use of organic and inorganic fertilizer seems to be vital (Hegde *et al.,* 1998). The application of inorganic fertilizers (NPK) in combination with biofertilizers had improved crop productivity and also maintained the soil fertility for sustainable crop production. Balanced use of nutrients through organic sources like farmyard manure (FYM), vermicompost, green manuring, neem cake and biofertilizers are prerequisites to sustain soil fertility and to produce a maximum crop yield with optimum input level. Application of chemical fertilizers along with enriched organic manure and biofertilizers could help in nourishing the living entities of soil, better holding of nutrients slow, release and help in soil transformation. With these idea, this experiment was conducted to find out the effect of integrated use of nutrients sources on growth, yield attributes, seed yield, oil content and soil nutrient status of castor.

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Material and Methods

The experiment was conducted at Tapioca and Castor Research Station, Yethapur during *Kharif* (2013-14). The location of the experimental plot was 11° 35' N latitude and 78° 29'E longitude with a mean annual rainfall of 850 mm that was bimodally distributed between June-September and October-December. The mean annual minimum and maximum temperature was 20° and 37°C, respectively. According to the USDA classification, the experimental soil belonged to Alfisol (red soil) -*Typic Rhodustalfs*. The soil was sandy loam in texture with pH of 7.90, EC of 0.39 dS m^{-1} and organic carbon content of 0.54%. The soil was medium in available N (227 kg ha^{-1}), high in available P (24.1 kg ha^{-1}) and available K (269 kg ha^{-1}).

Preparation of enriched organic materials

The required quantity of different organic

materials (farmyard manure, poultry manure, vermicompost, pressmud compost and coirpith compost) were subjected to enrichment process by adding them separately, to 50% and 100% of the recommended dose of P fertilize, thoroughly mixed and heaped. The heap was covered with polyethylene sheet and incubated at 80% moisture for 45 days to obtain enriched form of organic manures *viz*., enriched farmyard manure (E-FM), enriched poultry manure (E-PM), enriched vermicompost (E-VC), enriched pressmud compost (E-PC) and enriched coirpith compost (E-CC). Apart from treatments T1 and T2, in all other treatments, biofertilizers (*Azospirillum* and *Phosphobacteria*) were applied at 2 kg ha^{-1}. The nutritive values of the manures were analysed before and after enrichment using APHA, (1989) methods (Table1 and 2).

The experiment was laid out in a randomised block design with three replicates. The treatment consisted of five organic manures and two levels of inorganic fertilizers *viz*., T_1-Control; T_2-Recommended dose of fertilizer (RDF) (45:15:15 kg NPK ha^{-1}); T_3-RDF + E-FM @750 kg ha^{-1} + *Azospirillum* and *Phosphobacteria* ; T_4-50% RDF + E-FM @ 750 kg ha^{-1} + *Azospirillum* and *Phosphobacteria*; T_5-50% RDF + E-PM @ 750 kg ha^{-1} + *Azospirillum* and *Phosphobacteria*; T_6-50% RDF + E-VC @ 750 kg ha^{-1} + *Azospirillum* and *Phosphobacteria*; T_7-50% RDF+ E-PC @ 750 kg ha^{-1} + *Azospirillum* and *Phosphobacteria* and T_8-50% RDF + E-CC @ 750 kg ha^{-1}+ *Azospirillum* and *Phosphobacteria.*

For basal application, half the dose of N and entire dose (50 % or 100 % as per the treatment) of P_2O_5 and K_2O were applied. On 60 DAS, the other half dose of N was top dressed. The enriched manures were applied to the plots before sowing castor hybrid YRCH 1 at a seed rate of 5 kg ha^{-1} with 90 x 90 cm spacing. Until the harvest of the crop, all other cultural operations were followed as per the recommendations of crop production guide of Tamil Nadu Agricultural University (http://agritech.tnau.ac.in/agriculture/oilseeds_castor.html).

Growth, yield attributes, yield and oil content

The influence of enriched organic materials were observed with respect to plant height, yield attributes, economic yield, oil content and nutrient content of the soil. The plant height was measured at primary spike formation stage. The days taken to obtain 50% flowering was counted during the primary spike flowering stage. After the harvest, the number of spikes per plant, effective spike length and hundred seed weight per treatment and seed yield per net plot area were recorded (Table 3). The oil percentage was determined as per A.O.A.C. (1970) procedure using dried seeds and petroleum ether as a solvent.

Soil chemical analysis

The soil sample was collected from each plot, after the harvest of the crop at a depth of 0-15 cm and used for determining the pH, EC, organic carbon and nutrient status. The soil pH was measured in soil slurry prepared from soil: water ratio of 1:2.5, the available N was determined by alkaline permanganate method, available P was analysed by Olsen method and available K was measured by neutral normal ammonium acetate extract method (Table 4). The data on various parameters studied during the investigation were statistically analysed by the method suggested by Gomez and Gomez (1984). The critical difference was worked out at 5 per cent (0.05) probability levels.

Results and Discussion

Crop responses to integrated nutrient management (INM) with enriched manures

Growth and yield attributes

Among all the treatments, the organic amendments were found to influence crop growth. The increase in plant height in various treatments ranged from 58.5 to 116.6 cm. Application of 100% RDF with E-FM and biofertilizer (*Azospirillum* and *Phosphobacteria*) recorded the highest plant height of 116.6 cm followed by the treatment with 50% RDF + E-PM and biofertilizers 96.6 cm. Significant difference was not observed on the primary spike flowering ability especially with 50% flowering (Table 3). The effect of combined application of organic and inorganic sources of nutrients and biofertilizers on the growth, yield and oil content are presented in Table 3. The number of spikes per plant ranged from 12.0 to 18.0.

Table 1. Physicochemical characteristics of the organic materials

Characters	FYM	Poultry manure	Coir dust	Vermi compost	Press mud
pH	7.05	6.88	6.80	7.52	7.23
EC (dS/m)	0.54	2.03	2.10	0.50	1.70
Organic carbon (%)	20.0	24.0	25.0	18.0	29.6
Nitrogen (%)	0.52	2.4	0.88	1.36	1.15
Phosphorus (%)	0.24	1.86	0.12	0.30	2.12
Potassium (%)	0.36	1.34	1.02	0.42	0.80
Calcium (%)	0.18	3.6	0.35	0.26	0.21
Magnesium (%)	0.12	0.08	0.48	0.08	0.08

Among the treatments, 100% RDF with E- FM and biofertilizer treatment resulted in increased number of spikes (18.0) per plant followed by 50% RDF with E-PM and biofertilizers. The results of treatments, those that received 50% RDF with enriched manures (FYM, vermi compost, pressmud) and biofertilizers were found to be comparable with each other. The effective spike length increased in all the treatments which ranged from 45.0 cm to 59.0 cm. The longest length (59.0 cm) of the spike was recorded in 100% RDF with E- FM and biofertilizers application. No significant difference was observed

Table 2. Physicochemical characteristics of the enriched organic materials

Characters	FYM	Poultry manure	Coir dust	Vermi compost	Press mud
pH	7.11	6.96	6.75	7.58	7.32
EC (dS/m)	0.68	2.53	2.40	0.70	1.90
Organic carbon (%)	20.6	23.6	24.0	18.0	28.8
Nitrogen (%)	0.59	2.51	1.02	1.42	1.21
Phosphorus (%)	1.09	2.52	0.99	1.15	2.75
Potassium (%)	0.32	1.18	0.90	0.37	0.71
Calcium (%)	0.16	3.18	0.31	0.23	0.19
Magnesium (%)	0.11	0.07	0.42	0.07	0.07

Table 3. Effect of enriched organic materials on growth, yield and oil content of castor

Treatment details	Plant height (cm)	Days to 50% flowering	No. of spikes	Effective spike length (cm)	100 seed weight (g)	Seed yield (kg ha^{-1})	Oil content (%)
T1	58.5	52.0	12.0	45.0	31.2	962	42.56
T2	85.6	50.0	16.0	54.0	32.4	1585	48.12
T3	116.6	48.0	18.0	59.0	33.8	1785	48.56
T4	78.5	50.0	15.0	53.0	32.5	1492	47.98
T5	96.6	49.0	17.0	56.0	33.8	1592	48.23
T6	77.2	50.0	15.0	52.0	32.9	1489	47.12
T7	83.4	49.0	15.0	53.0	33.6	1498	47.32
T8	73.3	52.0	14.0	51.0	32.9	1481	47.15
Mean	83.7	50.1	15.3	52.9	32.7	1475	47.13
SEd	2.19	1.23	0.42	1.36	0.84	38.10	1.20
CD (0.05)	4.69	NS	0.91	2.91	NS	81.72	2.57

with respect to 100 seed weight among the treatments. Senthil Kumar and Kanjana, (2009) reported that application of FYM @ 12.5 t ha^{-1} with biofertilizers had increased the yield parameters like length of primary spike, number of spikes/plant and capsules/ spike. Effect of organic and inorganic fertilizers along with biofertilizers on crop growth was highlighted in a study conducted by Duhoon *et al.* (2001). On kharif sesame, they observed a significant increase in the number of capsules per plant, grain yield and haulm yield. Filho *et al*. (2013) also reported that application of organic nutrition brought positive results in the vegetative and economic growth of the castor bean plant. Another study also showed the importance of organic manuring. It was conducted in castor – sorghum cropping system by Patel *et al.* (2007) which showed that organic sources supply micro nutrients and growth promoting substances, that might have helped in increasing the number of branches/plant and length of primary spike in turns increasing the seed yield.

Seed yield and oil content

The effect of different enriched organic manures and inorganic fertilizers along with biofertilizers on castor yield and oil content is presented in Table 3. Application of enriched organic manures and bioinoculants with inorganic fertilizers significantly influenced the yield. The highest seed yield of 1785 kg ha^{-1} and oil content of 48.56% was recorded with application of 100% RDF and enriched FM and biofertilizers followed by application of 50% RDF with E-PM and biofertilizers (1592 kg ha^{-1} and 48.23%) and in RDF alone treatments (1585 kg ha^{-1} and 48.12%), respectively. These results corroborate with the findings of Patel *et al.* (2010). Similar result was also observed by Senthil Kumar and Kanjana (2009), when the FYM @ 12.5 t ha^{-1} and biofertilizers (*Azospirillum*

and *Phosphobacteria*) were applied to the castor field. Thus, several studies had documented the importance of enrichment of FYM and their use in rainfed castor. In the present study, application of 50% RDF with E-PM amended with *Azospirillum* and *Phosphobacteria* resulted in yield of 1592 kg ha^{-1}. This yield was found to be on par with that of the RDF alone treatment (1585 kg ha^{-1}). This results clearly depicted that the application of organic amendments could increases the availability of nutrients to the crop. Mavarkar *et al.* (2009) also confirmed that compared to RDF alone treatment, combined application of RDF with poultry manure @ 3 t ha^{-1} had significantly increased the bean and oil yield in castor.

Soil chemical analysis

Effect of INM on soil pH and EC

Due to the application of enriched manures with inorganic fertilizers and bioinoculants, changes were imparted in soil pH and EC (Table 4). Visibly, no significant difference was observed in soil pH due to the application of enriched organic manures and bioinoculants. However, these treatments positively influenced the soil EC which varied from 0.38 to 0.43 dS/m. The highest EC was recorded in treatment with RDF + E-FM along with biofertilizers (0.43 dS/m). In all the treatments containing enriched manure as a component, a slight increase in soil EC was observed. Omar Hattab, (2000) also found increase in EC level and hypothesized that during the decomposition of the constituents of the pressmud, the CO_2 level increased resulting in carbonic acid production in turn leached the salt into the soil solution resulting in increased EC level.

Effect of INM on organic carbon

The organic carbon in soil was significantly changed due to the application of enriched organic manures and bioinoculants (Table 4). The level of organic carbon increase from 0.52% in RDF plots to 0.58% in 50% RDF with E-PC and biofertilizers amended treatments. This is in line with the findings of Ismail *et al.* (1994) who reported a significant increase in organic C content of the soil with the application of FYM, possibly due to its decomposition.

Table 4. Effect of enriched organic materials on the major nutrients content of the soil

Treatment details	pH	EC (dS/m)	Organic carbon (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T1	7.80	0.38	0.50	202	18.00	256
T2	7.80	0.40	0.52	248	26.02	278
T3	7.80	0.43	0.56	262	28.02	284
T4	7.90	0.40	0.56	236	25.30	272
T5	7.80	0.42	0.54	242	26.00	284
T6	7.80	0.39	0.54	236	24.28	276
T7	7.70	0.42	0.58	242	26.00	284
T8	7.90	0.41	0.54	230	24.08	272
Mean	7.81	0.41	0.54	237	24.71	275
SEd	0.20	0.01	0.02	5.93	0.63	7.14
CD (0.05)	NS	0.02	0.04	12.72	1.34	15.31

Effect of INM on available fractions of macronutrients N, P and K

Application of enriched organic manures had increased the soil N (Table 4). The treatment with 100% RDF with E-FM and biofertilizers recorded the highest N content of 262 kg ha^{-1}.The concentration of available P was markedly influenced by the application of enriched organic manure and bioinoculants (Table 4). Irrespective of the treatments the available P in soil was found to increase significantly. In 100% RDF with E-FM and biofertilizers the highest available P (28 kg ha^{-1}) was recorded.

Change in the available K in soil was also influenced by organic manuring (Table 4). The potassium concentration varied between 256 kg ha^{-1} to 284 kg ha^{-1}. The treatment with 100% RDF + E-FM + *Azospirillum* and *Phosphobacteria* recorded the highest potassium content of 284 kg ha^{-1}. Incorporation of FYM @12.5 t ha^{-1} along with zinc solubilising bacteria stood superior to FYM alone and control treatments by registering the highest values for the availability of N, P and K in the soil (Senthil Kumar *et al.,* 2004).

INM plays an integral role in sustainable agriculture without deteriorating the quality of environment and conserving vital natural resources. Several studies clearly showed the integration of chemical, organic and biofertilizers in INM. Pooran *et al.* (2002) proved that application of 50% RDF with FYM had supplied around 25% N requirement. Further inoculation of *Azospirillum* and PSB gave higher yield. In a recent study, *rabi* castor (var. GCH7) crop fertilized

with 75% N through inorganic fertilizer and 20 % N through biocompost secured higher production and income (Nitin Gudadhe *et al.,* 2017). This study clearly showed the importance of biofertilizers (*Azospirillum* and *Phosphobacteria*) amended with organic manures and inorganic fertilizers could increase the yield of castor.

Conclusion

The results of the present study indicated that application of recommended dose of fertilizers (45:15:15 kg NPK/ha) and enriched farmyard manure @ 750 kg ha^{-1} along with *Azospirillum* and *Phosphobacteria* at 2 kg ha^{-1} had recorded the highest seed yield (1785 kg ha^{-1}) and oil content (48.5%) in castor. All enriched organic manures (E-PM, E-VC, E-PC and E-CC) could also significantly increase the yield. In addition, the recommended dose of fertilizers (45:15:15 kg NPK/ha) with enriched farmyard manure was found to impart significant changes in the soil EC and macronutrients (NPK) status. Hence the combined use of organic, inorganic and biofertilizers in recommended to ascertain the balanced nutrition in castor to sustain the productivity, yield and oil content.

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