

ACCEPTED ARTICLE

Castor (*Ricinus communis* L.) and Cucurbits relay intercropping system for enhancing resource conservation and productivity

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ABSTRACT

Sustainable improvements in agricultural production and productivity necessitate efficient resource utilization; relay intercropping can improve crop yield and land productivity while using fewer inputs. Thus, in a three year field trial, different cucurbit vegetable crops were tested to see if they were suitable for relay intercropping with castor (*Ricinus communis* L.). These treatments encompassed various intercropping strategies involving castor, each paired with a different cucurbits **such as** bitter gourd (*Momordica charantia*), ridge gourd (*Luffa acutangula*), snake gourd (*Trichsanthus cucumerina*), bottle gourd (*Legenaria siceraria*), coccinia (*Trichsanthus dioica*), and cucumber (*Cucumis sativus*). **The results showed that the castor** and cucumber relay intercropping systems produced the highest castor equivalent yield (1701 kg ha⁻¹), followed by castor and ridge gourd (1596 kg ha⁻¹). Among all the cucurbit intercropping systems, the castor + cucumber relay system had the highest productivity (4.66 kg/ha/day), profitability (4.07 \$/ha/day), and relative economic efficiency (198.5%). The best moisture-use efficiency was achieved by castor and bitter gourd relay intercropping (6.58 kg/ha/mm), followed by castor and bottle gourd relay intercropping (6.35 kg/ha/mm). There was a higher net return for relay intercropping of castor and cucumber (\$ 1483.9 ha⁻¹), followed by castor and ridge gourd (\$ 1446.2 ha⁻¹). Sole castor produced 1312 kg ha⁻¹, despite its low monetary returns of \$ 501.6 ha⁻¹. It has been found that relay intercropping between castor and ridge gourd (3.29), followed by castor and bitter gourd (3.29), produces the highest benefit-cost ratio. As a result, the relay intercropping system, which determines the competitive interaction and productivity of castor and cucurbits, can provide the greatest benefits.

Keywords: Oilseeds, Vegetables, Intercropping, Moisture.

INTRODUCTION

Mixed cropping, unlike monoculture, fosters biodiversity, soil health, and resilience to pests and climate change. It enhances ecological balance, reduces chemical inputs, and promotes sustainable agriculture. Through diverse crop combinations, it sustains

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34 **ecosystems, supports farmers' livelihoods, and ensures food security in the face of**
35 **environmental challenges.** Castor (*Ricinus communis* L.), a significant oilseed crop renowned
36 for its industrial applications worldwide, faces challenges such as poor soil fertility and
37 unpredictable, erratic rainfall patterns, which elevate the risk of crop failure in traditional
38 solitary farming approaches. To mitigate these risks, intercropping, defined as the simultaneous
39 or sequential cultivation of multiple crop species on the same land area, emerges as a promising
40 strategy to enhance resilience and reduce the vulnerability of crops. Intercropping uses multiple
41 crops sown and harvested at the same time, while relay intercropping uses intercrops with
42 different growth stages Raza *et al.*, 2019. Notably, relay intercropping, identified as a form of
43 biological insurance against climatic uncertainties in regions with unusual weather conditions
44 by Koli *et al.* (2004), presents an intriguing avenue for safeguarding crop yields. **Castor,**
45 **adaptable as both a mixed or intercrop and a standalone crop, exhibits characteristics**
46 **conducive to intercropping systems owing to its generous inter and intra row spacing**
47 **(Vaghela et al, 2019). In rainfed and irrigated settings, castor finds application as a border**
48 **crop or live fencing, enriching its versatility. However, the realm of cucurbit**
49 **intercropping within the castor ecosystem remains relatively unexplored, with limited**
50 **investigations in India comparing castor intercropping with cucurbit vegetable crops.**
51 **Intercropping, while offering advantages, also introduces the challenge of resource**
52 **competition among plants (Mohsin et al, 2018).** Raza *et al.*, 2022 described that intercropping
53 system can save 20-50 % of water and land, especially under the present scenario of limited
54 resources and climate change. This higher and stable yield, particularly with reduced inputs,
55 are mainly ascribed to resources complementarity (Raza *et al.*, 2019), in which intercrop species
56 utilize available resources more adequately due to different spatial (Raza *et al.*, 2021), temporal
57 and phonological characteristic (Li *et al.*, 2013).

58 Distinguishing itself from conventional intercropping methods, relay cropping systems entail
59 the cultivation of two or more crops on the same bed at distinct time intervals, ensuring the
60 second crop is sown after the first has matured. This approach potentially mitigates rivalry,
61 especially concerning the main crop, in contrast to other intercropping techniques like mixed
62 intercropping strips **(Keshavamurthy and Yadav, 1997).** Within the context of castor farming
63 areas, leguminous intercrops such as black gram, green gram, and groundnut hold pivotal roles
64 in enhancing food security, revenue generation, and environmental preservation. While cucurbit
65 relay intercropping hasn't been extensively integrated with castor, a comprehensive scientific
66 exploration of productivity and potential economic gains within each relay intercropping
67 system is notably absent. It becomes imperative to identify dependable relay intercropping

68 systems to ensure the sustainable utilization of natural resources while upholding and
69 optimizing productivity. In light of these considerations, the present study embarks on an
70 exploration to evaluate various cucurbit species as potential relay intercrops within widely
71 spaced castor rows, forming the foundation of a resilient and resource-efficient castor-based
72 relay intercropping system. **The objectives of this study were to investigate the effect of
73 castor-cucurbits relay cropping on the growth, yield attributing characters and yield of
74 cucurbits for higher resource use efficiency, system productivity and monetary returns.**

75 MATERIALS AND METHODS

76 Site Description and Experimental Design

77 The Tapioca and Castor Research Station in Yethapur, Tamil Nadu, India situated at
78 coordinates 11.6627° N, 78.4751° E, and an altitude of 200 meters **above mean sea level,**
79 served as the backdrop for a comprehensive three-year field experiment spanning the *Kharif*
80 seasons of **2020-2021, 2021-2022 and 2022-2023. Sowing of castor was on August 23rd in
81 2020 (1st year), August 28th in 2021 (2nd year), September 4th in 2022 (3rd year), Castor was
82 harvested on January 25th in 2021(1st year), January 22nd in 2022 (2nd year), January 28th
83 in 2023 (3rd year). Following the castor harvest, the castor plants were pruned (removing
84 the terminal shoots and foliage) and cucurbits were sown in between the castor plants on
85 the following dates. Sowing dates for cucurbits were February 10th, 2021 (1st year),
86 February 12th, 2022 (2nd year) and February 16th, 2023 (3rd year). Cucurbits crops were
87 harvested on July 3rd in 2021(1st year), July 10th in 2022 (2nd year), July 12th in 2023 (3rd
88 year). Nestled within a tropical landscape, this region is characterized by its distinct wet and
89 dry seasons, with bimodal rainfall exceeding 980 mm. Against this backdrop, an elaborate
90 agricultural study was meticulously carried out. The foundation of this research was rooted in
91 a randomized block design, incorporating seven distinct treatments replicated three times.
92 These treatments encompassed various intercropping strategies involving castor, each paired
93 with a different cucurbits: **T₁-Castor sole (YTP-1), T₂-Castor-Bitter gourd (*Momordica*
94 *charantia*), T₃-Castor-Ridge gourd (*Luffa acutangula*), T₄-Castor-Snake gourd
95 (*Trichsanthus cucumerina*), T₅-Castor-Bottle gourd (*Legenaria siceraria*), T₆-Castor-
96 *Coccinia* (*Trichsanthus dioica*), T₇-Castor-Cucumber (*Cucumis sativus*).** The key variety
97 of castor utilized was the cultivar YTP 1, and optimal spacing recommendations of 3 × 3 meters
98 for castor and 2.5 × 2.5 meters for cucurbits were diligently adhered to. The experiment was
99 inaugurated during the *Kharif* growing season.
100**

101 Average seasonal (June–January) rainfall during the experimental period was 968 mm. **Table**
102 **1 shows the monthly climatic conditions at the experimental site for the growing season.**
103 Average annual maximum and minimum temperatures during the experimental period were
104 35°C and 21°C, respectively. Before the field experimentation, the soil samples were collected
105 to depths of 0–15 cm from each corresponding experimental unit and accurately analyzed to
106 determine the different physicochemical properties of the soil profile. The soil composition at
107 this experimental site exhibited characteristics of a clay loamy texture, with a pH value of 7.3.
108 Organic carbon content was found to be relatively low, measuring at 0.29%. The soil of the
109 experimental field was non-calcareous red soil, and with the **three**-year average available
110 nutrient status of the experimental site, it was low in available N (216 kg ha⁻¹) and high in
111 **available P and available K** (26.0 kg ha⁻¹ and 364 kg ha⁻¹). Armed with this understanding, the
112 research team implemented an array of innovative agronomic techniques to optimize crop
113 performance. Notably, a unique approach was adopted in the form of "nipping" at the 10th node,
114 carried out around 42 days after sowing (DAS), which effectively promoted branching and
115 subsequent productivity. This was complemented by a meticulous pruning regimen, wherein
116 each primary and secondary branch retained seven nodes. This pruning practice was applied
117 immediately after harvesting spikes of secondary, third, and fourth orders, leading to enhanced
118 branching dynamics per plant and an overall uptick in productivity. Intriguingly, the
119 arrangement of cucurbit seeds was orchestrated along the bunds, placed at a distance of 0.5
120 meters from the main castor trunk (YTP 1). This ingenious setup facilitated the cultivation of
121 cucurbits at a spacing of 2.5 × 2.5 meters, thereby streamlining intercultural operations for both
122 castor and cucurbits. Moreover, irrigation channels, each spanning a width of 50 cm, were
123 thoughtfully established between adjacent rows of castor (3m × 3m), ensuring optimal water
124 management. Throughout the course of this extensive experiment, all procedures and
125 methodologies were meticulously executed in accordance with established cultural norms and
126 agricultural practices.

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135 **Table 1.** A synopsis of weather conditions in 2020-2023 growing seasons.

| Month | Precipitation (mm) | | |
|-----------|--------------------|---------|---------|
| | 2020-21 | 2021-22 | 2022-23 |
| January | 0 | 7.8 | 2.6 |
| February | 0 | 13.8 | 0 |
| March | 0 | 99.8 | 9.8 |
| April | 56.2 | 46.4 | 6.4 |
| May | 41 | 61.4 | 65 |
| June | 50.2 | 36 | 19.8 |
| July | 83.8 | 131.6 | 30 |
| August | 212.2 | 245 | 60.2 |
| September | 54 | 60.6 | 36.8 |
| October | 218.8 | 170 | 10.8 |
| November | 56 | 334.7 | 185.6 |
| December | 151 | 33.9 | 77.2 |
| Total | 923.2 | 1241 | 504.2 |

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137 **Measurements and analytical procedures**

138 Based on current market pricing (\$ kg⁻¹), **Castor Equivalent Yield (CEY)** was determined
 139 as the castor yield of all intercropping regimens. The formula suggested by Lal and Ray (1976)
 140 was used to calculate it.

$$\text{Castor equivalent yield (CEY)} = \frac{\text{Yield of intercrop} \times \text{Price of intercrop (\$)}}{\text{Price of castor (\$)}} \times 100$$

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142 The determination of the Land Equivalent Ratio (LER) was a crucial facet of the study,
 143 involving the utilization of the following mathematical expression:

$$\text{LER} = (\text{AI/AS}) + (\text{BI/BS})$$

144 In this equation, LA and LB symbolize the respective LERs attributed to two distinct crops,
 145 denoted as A and B. The computation of LA is accomplished by dividing the yield of crop A in
 146 an intercropping arrangement (AI) by the yield of the same crop A when grown individually
 147 (AS). This identical formula is equally applied to derive the LER for LB, following the
 148 methodology established by Vandermeer (1989).
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150 Moisture Use Efficiency is an operationalized concept for resource use efficiency and is a
 151 common metric used to assess ratio of plant production to water consumed. The evaluation of
 152 Moisture Usage Efficiency (MUE) constituted an additional significant parameter, ascertained
 153 by dividing the cumulative water consumption (measured **as mm**) spanning the period from
 154 planting to harvest by the achieved **seed yield** (expressed in kilograms per hectare). This pivotal
 155 metric was computed in line with the framework outlined by Sharma and colleagues, 2013.
 156 Furthermore, a comparative assessment of economic enhancements vis-à-vis the prevailing
 157 agricultural system was determined through the lens of Relative Economic Efficiency (REE).
 158 This assessment sheds light on the economic viability and gains brought about by the proposed

159 interventions, providing insights into the economic effectiveness of the different cropping
160 strategies under scrutiny.

$$\text{REE (\%)} = \frac{\text{Net income from improved system} - \text{Net income in existing system}}{\text{Net income in existing system}} \times 100$$

161 As elucidated by Tomar and Tiwari (1990), the concept of system profitability pertains to the
162 monetary gain engendered by the cultivated crops. Net returns, quantified on a per-hectare
163 basis, find expression in rupees per hectare per day (\$/ha/day). System productivity, on the
164 other hand, involves the conversion of diverse crop yields into a unified equivalent yield for a
165 single crop, denominated in **kg per ha per day. For the calculation of net revenue per hectare,**
166 **the gross return per hectare was meticulously offset by the total cost of cultivation. In**
167 **tandem, the assessment of benefit-cost ratio was executed by dividing the gross returns by**
168 **the corresponding cost of cultivation. These financial metrics collectively offer insights**
169 **into the economic viability and profitability of the agricultural system under**
170 **consideration.**

171 **Statistical analysis**

172 To assess the significance of treatment effects on the diverse parameters under scrutiny,
173 Analysis of Variance (ANOVA) was methodically conducted. In cases where the treatment
174 means displayed notable disparities, the Least Significant Difference (LSD) method was aptly
175 employed to discern the nuanced differences among the means. The analytical approach
176 outlined by Gomez and Gomez (1984) was skilfully applied to facilitate this statistical analysis.

177 **RESULTS AND DISCUSSION**

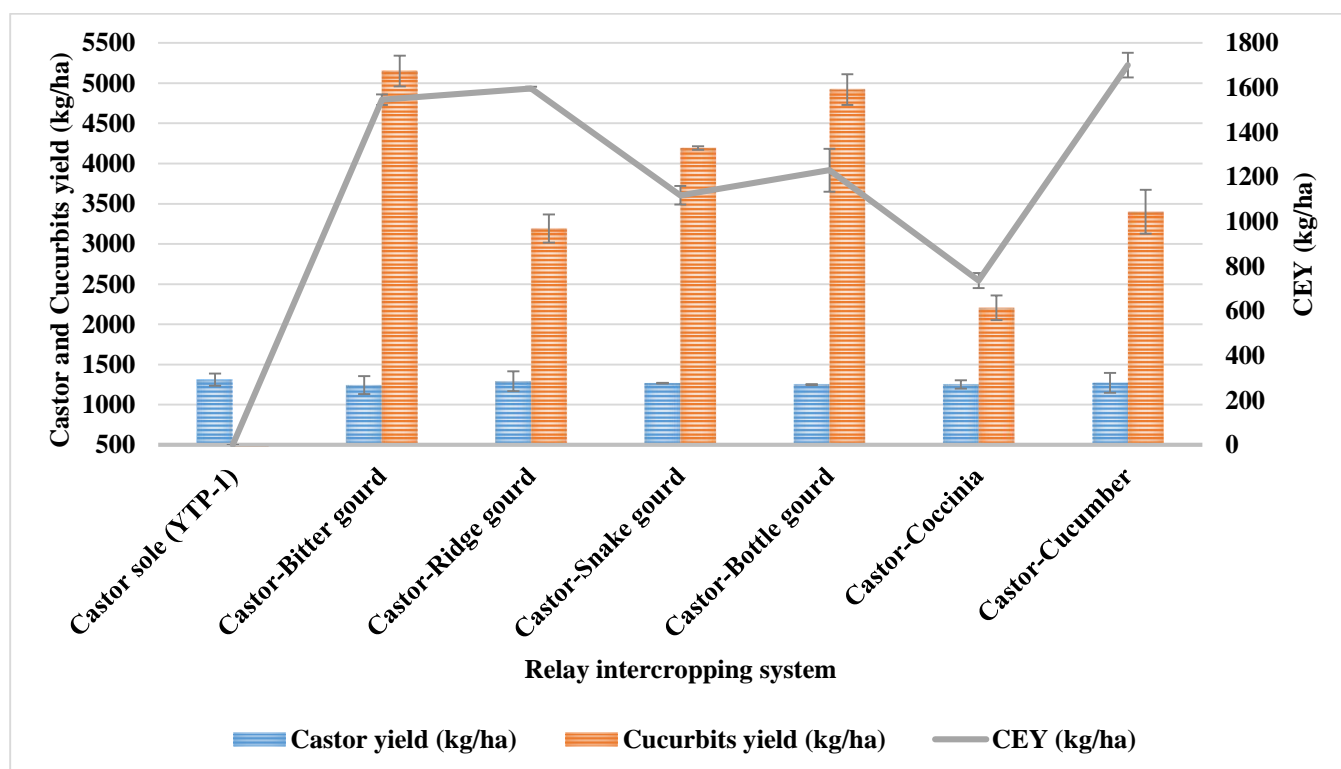
178 **Growth and yield parameters of castor**

179 The findings of the study unveiled that the utilization of diverse relay intercropping systems
180 had minimal discernible impact on the growth and yield attributes of castor, as outlined in Table
181 2. Among the observed parameters, the towering stature of castor plants was most pronounced
182 in the context of sole cultivation, reaching an impressive height of 152.3 **cm**. Following closely
183 behind, the castor-snake gourd relay intercropping system exhibited a commendable plant
184 height of 148.5 **cm**. In terms of branch development, it was intriguing to note that the castor-
185 snake gourd relay intercropping and standalone castor systems demonstrated the highest branch
186 proliferation rates, boasting 14.2 and 14.9 branches per plant, respectively. Remarkably, the
187 productivity of castor itself appeared relatively unscathed by the incorporation of cucurbits in
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190 relay intercropping configurations, as indicated in Table 2. A detailed analysis (Figure 1)
 191 showcased that the various relay intercropping setups did not exert significant influence on the
 192 castor yield. In fact, the solo castor cultivation exhibited the most impressive seed output,
 193 culminating in a remarkable 1,312 kg ha⁻¹.

194 It is worth noting that the lack of substantial divergence in the yield of castor across the diverse
 195 intercropping strategies might stem from several underlying factors. One potential explanation
 196 could be the equitable distribution and utilization of available resources among the crops,
 197 leading to a balanced competition for essential elements like nutrients, water, and sunlight.
 198 Alternatively, this outcome could be attributed to a strategic farming approach where cucurbits
 199 are selectively cultivated, thereby avoiding potential resource conflicts with the castor. These
 200 findings find resonance with previous research conducted by Srilatha and colleagues (2002)
 201 who investigated castor intercropped with leguminous systems and arrived at analogous
 202 conclusions. The apparent similarity in outcomes across different studies underscores the
 203 consistency of these observations and provides valuable insights into the intricacies of
 204 intercropping dynamics within the realm of agricultural practices.

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207 **Figure 1.** Mean comparisons for castor – cucurbits yield affected as relay intercropping.

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211 **Cucurbits yield and system productivity**

212 Upon conducting a comprehensive pooled analysis, intriguing insights emerged regarding the
213 interplay between castor and various studied cucurbits. Among the assortment of cucurbits
214 scrutinized, the castor + bitter gourd relay intercropping arrangement stood out as a notable
215 performer, yielding an impressive 5,151 kg ha⁻¹. This heightened yield of bitter gourd can be
216 predominantly attributed to its intrinsic capacity for prolific production, surpassing its cucurbit
217 counterparts (Figure 1). An intriguing aspect contributing to this success is the trailing nature
218 of the bitter gourd climber, which adroitly navigates and weaves through the branches of the
219 castor plant. This growth pattern not only enhances resistance to pests and diseases but also
220 circumvents ground-level contact, mitigating soil-related vulnerabilities. A similar observation
221 was documented by Schultz *et al.*, 1982, wherein intercropping cucumber and tomato was
222 shown to be beneficial compared to monoculture, aligning with the principle that associating
223 crops can often harness resources more efficiently, ultimately translating into higher yields.

224 Further probing the realm of system productivity, two distinct intercropping systems
225 demonstrated exceptional performance. The castor-cucumber relay intercropping system,
226 recording a system productivity of 4.66 kg/ha/day, and the castor-ridge gourd system, boasting
227 a commendable 4.37 kg/ha/day, emerged as frontrunners in this domain. Contrastingly, the
228 castor-snake gourd system (Table 2) lagged behind, yielding a comparatively lower system
229 productivity of 3.06 kg/ha/day. This divergence can be attributed to the relatively lower fruit
230 yields observed in the case of snake gourd, despite its favorable market prices in cucumber. The
231 findings echoed the research of Koli *et al*, 2004, underscoring the correlation between better
232 net returns and enhanced system productivity within castor-based intercropping systems.
233 Collectively, these observations underscore the potential inherent in the relay intercropping
234 approach, particularly in the context of castor and cucumber. This positive outcome implies a
235 judicious utilization of resources, leading to heightened efficiency, and notably, a reduction in
236 competition among castor plants.

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238 **Castor Equivalent Yield (CEY) and Land Equivalent Ratio (LER)**

239 A crucial aspect of the study was the conversion of the yield obtained from each individual
240 crop into Castor Equivalent Yield (CEY), a parameter that was calculated based on prevailing
241 market prices. This conversion allowed for a comprehensive evaluation of the relative
242 efficiency of various treatment combinations. Notably, the castor-ridge gourd relay
243 intercropping system emerged as a standout performer in terms of CEY, registering a
244 significantly higher output of 1596 kg ha⁻¹ compared to the sole cultivation of castor (Figure

245 1). This result underscored the potential profitability and productivity of relay intercropping,
246 particularly evident in the castor and ridge gourd pairing.

247 This conclusion found resonance with earlier research conducted by Padmavathi and
248 Raghavaiah (2004), who similarly observed advantageous outcomes in castor combined with
249 cluster bean intercropping systems. The marked increase in castor equivalent yield was
250 primarily attributed to the complementary nature of the intercrop, which contributed an
251 additional yield without causing substantial reduction in the primary crop's output. These
252 findings harmonized with the research conducted by Tanunathan *et al.*, 2006. Among the
253 diverse relay intercropping systems assessed, the castor-bitter gourd combination stood out,
254 boasting a notably higher Land Equivalent Ratio (LER) of 1.81 when compared to other
255 intercropping systems. This metric indicated that a relay intercropping setup demanded 81%
256 less land than a pure cropping system to achieve an equivalent yield. Conversely, the castor-
257 coccinia relay intercropping system exhibited the lowest LER, implying that its intercropping
258 advantage was relatively diminished. When assessed with the land equivalent ratio (LER), the
259 productivity benefits of relay intercropping systems are often higher than those of intercrops,
260 because under intercropping systems, both intercrops have the same growth stages and the
261 competition to use land, light, water, and nutrients is high. In contrast, in relay intercropping
262 systems, both intercrops have different growth stages, and the competition for available
263 resources is less (Raza *et al.*, 2019).

264 The observation of an LER value exceeding 1.00 indicated the advantage of intercropping
265 over sole stands in terms of optimized utilization of environmental resources for plant growth,
266 aligning with the principles established by Mead and Willey, 1980. This elevated LER value
267 elucidated the prevalence of interspecific interaction and complementarity, wherein the benefits
268 derived from cooperative growth exceeded the competitive pressures. This finding aligned with
269 the perspectives put forth by Mohammadi Nassab *et al.*, 2011 and Zhang *et al.*, 2011,
270 highlighting the inherent land-use efficiency and productivity advantages associated with well-
271 structured intercropping systems.

272 **Moisture Use Efficiency (MUE)**

274 The metric used to evaluate the performance of these intercropping systems is "moisture use
275 efficiency," which refers to the amount of biomass produced per unit of water used (kg/ha/mm).
276 The intercropping system that combined castor with bitter gourd recorded the highest moisture
277 use efficiency, with 6.58 kg/ha/mm. The second most efficient intercropping system was the
278 combination of castor and bottle gourd, with 6.35 kg/ha/mm. On the other hand, the lowest

279 moisture use efficiency of 1.27 kg/ha/mm was observed in the sole planting of castor without
280 any intercropping (Table 3).

281 The higher moisture use efficiency observed in the intercropping systems, especially with
282 bitter gourd, suggests that the combination of castor and bitter gourd is more effective in
283 utilizing available moisture from the soil compared to other intercropping combinations and the
284 sole castor crop. This might be attributed to the ability of bitter gourd to extract and utilize
285 water more efficiently from the soil, resulting in increased biomass production for both crops.
286 It's worth noting that similar findings were reported in a study conducted by Rao *et al.* 2010,
287 further supporting the idea that bitter gourd has a positive impact on moisture use efficiency
288 when intercropped with castor.

289

290 **Economics, Relative Economic Efficiency (REE) and System Profitability (SP)**

291 When examining the array of cucurbit-based relay intercropping systems, a distinct pattern of
292 economic returns emerged, shedding light on the financial advantages of certain combinations.
293 Notably, the relay intercropping arrangement involving castor and cucumber emerged as a
294 frontrunner, yielding significantly higher net returns amounting to \$ 1483.9 ha⁻¹. This was
295 closely followed by the castor and ridge gourd system, which yielded impressive net returns of
296 \$ 1446.2 ha⁻¹ (Table 3). These findings aligned harmoniously with the research conducted by
297 (Varghese, 2000) underscoring the positive impact of intercropping on vegetable productivity
298 per unit area and overall gross returns.

299 Delving into the economic efficiency metrics, it became apparent that certain relay
300 intercropping systems exhibited notably advantageous ratios. The castor + ridge gourd and
301 castor + bitter gourd systems achieved the highest benefit-cost ratios of 3.29, followed closely
302 by the castor + cucumber system with a ratio of 3.27. This phenomenon was in line with the
303 conclusions drawn by Sanwal *et al.*, 2006, who highlighted the heightened productivity and
304 growth benefits associated with intercropping, especially when coupled with vegetable crops.

305 In terms of Relative Economic Efficiency (REE), all the relay intercropping systems surpassed
306 the economic gain of sole castor cultivation. Among the relay intercropping systems, the castor
307 + cucumber arrangement stood out, recording the highest economic gain at an impressive 196%.
308 This was closely trailed by the castor-ridge gourd system, boasting an REE of 188% (Table 3).
309 This observation further resonated with the principle that diversifying the crop composition
310 within an existing system can amplify productivity, generate employment opportunities, and
311 consequently lead to heightened economic output, as articulated by Mukherjee, 2010.

312 Furthermore, the aspect of system profitability came to the fore, with the castor-cucumber
313 relay intercropping system attaining the maximum profitability at 4.07 \$/ha/day, closely
314 followed by the castor-ridge gourd system at 3.96 \$/ha/day. This variance in profitability can
315 be attributed to nuanced differences in factors such as yield, cultivation costs, and market prices
316 of the harvested produce within these relay intercropping sequences. These results were in
317 alignment with the conclusions drawn by Prasad, 2013, reinforcing the recurring theme of
318 enhanced economic viability and profitability in intercropping scenarios.

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Table 2. Growth characters of different castor - cucurbits based relay intercropping system (Pooled mean of three years).

| Relay intercropping system | Plant height (cm) | No. productive branches/plant | Spike length (cm) | No. of capsules/Spike | Shelling % | 100 seed weight (g) | Oil content (%) | Land Equivalent Ratio (LER) |
|----------------------------|--------------------|-------------------------------|-------------------|-----------------------|-------------------|---------------------|-------------------|-----------------------------|
| Castor sole (YTP-1) | 152.3 ^a | 14.9 ^a | 71.6 ^a | 111.1 ^a | 66.1 ^a | 43.3 ^a | 45.2 ^a | 1.00 ^c |
| Castor-Bitter gourd | 142.6 ^a | 12.5 ^a | 76.9 ^a | 113.6 ^a | 66.3 ^a | 43.2 ^a | 45.0 ^a | 1.81 ^a |
| Castor-Ridge gourd | 143.2 ^a | 12.8 ^a | 79.0 ^a | 111.8 ^a | 65.4 ^a | 43.2 ^a | 46.6 ^a | 1.78 ^a |
| Castor-Snake gourd | 148.5 ^a | 14.2 ^a | 73.2 ^a | 113.5 ^a | 65.8 ^a | 43.4 ^a | 46.1 ^a | 1.75 ^{ab} |
| Castor-Bottle gourd | 145.8 ^a | 13.6 ^a | 69.2 ^a | 117.2 ^a | 64.2 ^a | 43.2 ^a | 45.9 ^a | 1.76 ^{ab} |
| Castor-Coccinia | 139.3 ^a | 12.4 ^a | 70.9 ^a | 114.1 ^a | 66.5 ^a | 43.1 ^a | 45.6 ^a | 1.69 ^{ab} |
| Castor-Cucumber | 139.8 ^a | 13.2 ^a | 72.7 ^a | 112.5 ^a | 66.6 ^a | 43.0 ^a | 45.9 ^a | 1.70 ^{ab} |

320 ^a Mean±standard error for each trait; different letters indicate significant differences (LSD test, P< 0.05).

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322 **Table 3.** Economics, system productivity, profitability relative economic efficiency and moisture use efficiency of castor - cucurbits based relay
323 intercropping system (Pooled mean of three years).

| Relay intercropping system | Cost of cultivation (\$/ha) | Gross returns (\$/ha) | Net returns (\$/ha) | Benefit Cost Ratio | System productivity (kg/ha/day) | System profitability (\$/ha/day) | Relative Economic Efficiency (%) | Moisture Use Efficiency (kg/ha/mm) |
|----------------------------|-----------------------------|-----------------------|---------------------|--------------------|---------------------------------|----------------------------------|----------------------------------|------------------------------------|
| Castor sole (YTP-1) | 383.6 | 885.2 | 501.6 | 2.32 | - | 1.37 ^d | - | 1.27 ^d |
| Castor-Bitter gourd | 613.1 | 2007.6 | 1394.4 | 3.29 | 4.23 ^{ab} | 3.82 ^{ab} | 178 ^{ab} | 6.58 ^{ab} |
| Castor-Ridge gourd | 633.6 | 2079.7 | 1446.2 | 3.29 | 4.37 ^a | 3.96 ^a | 188 ^a | 4.62 ^a |
| Castor-Snake gourd | 596.9 | 1718.1 | 1121.2 | 2.88 | 3.06 ^b | 3.07 ^b | 124 ^b | 5.62 ^b |
| Castor-Bottle gourd | 641.0 | 1786.0 | 1145.0 | 2.79 | 3.37 ^b | 3.14 ^b | 128 ^b | 6.35 ^b |
| Castor-Coccinia | 595.7 | 1430.8 | 835.1 | 2.41 | 2.02 ^c | 2.29 ^c | 66 ^c | 3.56 ^c |
| Castor-Cucumber | 656.1 | 2140.0 | 1483.9 | 3.27 | 4.66 ^a | 4.07 ^a | 196 ^a | 4.81 ^a |

324 ^a Mean±standard error for each trait; different letters indicate significant differences (LSD test, P< 0.05).

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CONCLUSIONS

After an exhaustive three-year field investigation, the study firmly validates a notable phenomenon: the resilience of castor in relay intercropping systems with various cucurbit vegetable crops. This adaptability underscores castor's ability to coexist without yielding to competition. The relay intercropping of cucurbits positively impacts agricultural productivity and economic viability, evident in the remarkable increase in Castor Equivalent Yield (CEY) and enhanced system productivity, economic efficiency, and profitability. Particularly pronounced with cucumber, bitter melon, or ridge melon, relay intercropping demonstrates substantial yield advantages over sole castor cultivation. These findings highlight relay intercropping's potential to augment production, increase income, create employment opportunities, and enhance resilience against climatic uncertainties. As a multi-dimensional catalyst, relay intercropping not only benefits individual plots but also entire farming communities, driving positive changes towards a more secure and prosperous agricultural future.

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