agronomy

Article

Enhancing Cotton Production and Sustainability through Multi-Tier Cropping Systems: Growth, Efficiency, and Profitability Analysis

Kanthan Thirukumaran [1,*], Kadapillai Nagarajan [1], Natarajan Vadivel [2], Vaddi Saitheja [1], Venkatesan Manivannan [1], Gnanasekaran Prabukumar [1], Panneerselvam Parasuraman [1], Muthusami Karuppasami Kalarani [3], Ramasamy Karthikeyan [3] and Vaithiyanathan Sendhilvel [4]

1 Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641003, India; manivannanv@tnau.ac.in (V.M.)
2 Department of Cotton, Tamil Nadu Agricultural University, Coimbatore 641003, India
3 Directorate of Crop Management, Tamil Nadu Agricultural University, Coimbatore 641003, India; kalarani.mk@tnau.ac.in (M.K.K.)
4 Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641003, India
* Correspondence: thirukumaran@tnau.ac.in

Abstract: Intercropping presents an opportunity to optimise land use and resource efficiency in cotton cultivation, particularly for small and marginal farmers facing climate-related challenges and rising input costs. This study explores the potential of intercropping short-duration vegetables with cotton to transform this production system into a more economically viable and sustainable one. The study was conducted in the Cotton Department of Tamil Nadu Agricultural University in Coimbatore during the winter irrigated season, from August to January, in both 2020 and 2021. The growth, yield parameters, equivalent yield (3645 and 4234 kg ha^{-1}), and net return (Rs. 123,434 ha^{-1} and Rs. 154,034 ha^{-1}) were higher in the intercropping system with the paired row planting of Bt cotton with two rows of cluster bean. Upon comparing sole cropping and the paired row method of planting, it was found that adopting the paired row system of planting Bt cotton with two rows of cluster bean was highly profitable in all aspects of crop production. Therefore, the adoption of paired row cropping systems with compatible intercrops that promote synergistic effects on the main crop should be considered for enhancing overall productivity, as well as sustainability.

Keywords: cotton; paired row method; vegetables; cotton equivalent yield

Citation: Thirukumaran, K.; Nagarajan, K.; Vadivel, N.; Saitheja, V.; Manivannan, V.; Prabukumar, G.; Parasuraman, P.; Kalarani, M.K.; Karthikeyan, R.; Sendhilvel, V. Enhancing Cotton Production and Sustainability through Multi-Tier Cropping Systems: Growth, Efficiency, and Profitability Analysis. *Agronomy* **2024**, *14*, 1049. https://doi.org/10.3390/agronomy14051049

Received: 1 April 2024
Revised: 9 May 2024
Accepted: 13 May 2024
Published: 15 May 2024

1. Introduction

Cotton is the most important fibre and cash crop grown all over the Indian subcontinent in an area of around 12 million hectares, amounting to an average production of 35.9 bales (with each bale amounting to 170 kg of seed cotton) and a productivity of around 510 kg ha^{-1}. However, this yield lags far behind the global average lint yield, which accounts for 792 kg ha^{-1} [1]. Approximately, India produces around 25% of the total global lint, thus making it one of the prime producers of cotton. It has been reported that cotton plays an inevitable role in the Indian agricultural economy, supporting 60 million Indians through its supply and value chain. To meet the requirements of industries that depend on cotton, almost 15 million farmers are engaged in cotton cultivation [2]. In India, four species of cotton are cultivated, viz., *Gossypium hirsutum*, *G. barbadense*, *G. herbaceum*, and *G. arboretum*. Of these, *G. hirsutum* (American cotton) is cultivated to the maximum extent (97%). Almost two-thirds of the area under cotton cultivation in India is rainfed and, hence, the crop suffers from diverse abiotic stresses under such growing conditions. As cotton is a widely spaced crop, this provides an extensive scope for growing intercrops, subsequently maximising land use efficiency, hampering weed populations, and maximising gross and net returns, etc. Intercropping is the practice of growing or cultivating two or more crops concurrently on the same piece of land in such a way that the crops grown coexist for a specific time period, assuring temporal and spatial annidation [3–6]. The practice of intercropping is one of the most widely adopted agricultural interventions for enhancing the yield of crops and profitability per unit area [7]. Cotton-growing farmers, especially small and marginal growers, confront various constraints due to weather abnormalities and surges in the cost of inputs, which ultimately reduces their profit or returns. So, in order to tackle such circumstances, the concept of intercropping cotton with diverse agricultural or horticultural crops can be adopted, providing various advantages, viz., maximising returns, augmenting the quality of soil (if leguminous crops are included as an intercrop), improving biodiversity, ensuring the efficient utilisation of available resources, and curtailing risks from climate aberrations, thus limiting the probability of crop failure [4]. The total productivity and net income derived from intercropping systems exhibit significantly greater levels compared to monoculture cotton practices [8]. The agricultural income generated from various intercropping methods, which typically include cotton, increases by 30% to 40% [9]. As cotton is relatively a long-duration crop, its initial vegetative growth will be slow, which offers a wide scope for the inclusion of appropriate intercrops [10], including vegetable crops of a shorter duration. Usually, an ideal cotton-based multi-tier vegetable intercropping system intends to maximise the yield per unit area, enhance monetary returns, ensure the stability of production, and meet the domestic necessities of farmers. Crops like coriander, cluster bean, beetroot, radish, dolichos, and vegetable cowpea are highly preferred for multi-tier systems of intercropping with Bt (*Bacillus thuringiensis* L.) cotton, owing to the diverse features of these intercrops, viz., their growth habits, rooting patterns, root depths, and growth durations, etc. This pattern of the multi-tier intercropping of cotton with vegetables aims at the effective utilisation of resources, sustainability, and profitability. Considering these facts, a field experiment was conducted to study the effect of a multi-tier cropping system on cotton with the following objectives, 1. To study the growth and yield of Bt cotton a under multi-tier cropping system. 2. To evaluate the efficiency indices under this multi-tier cropping system 3. To study the profitability of multi-tier cropping systems.

2. Materials and Methods

2.1. Site Selected for the Experiment

A field experiment was conducted at the Department of Cotton, Tamil Nadu Agricultural University, Coimbatore, during the winter irrigated seasons (August–January) of 2020 and 2021. The experimental site is located at 11.23° N latitude and 77.10° E longitude at an altitude of around 428.5 m above MSL, which falls under the category of the western agro-climatic zone of Tamil Nadu.

2.2. Climate and Weather

Daily observations of weather parameters, viz., the maximum and minimum temperature, rainfall, relative humidity, wind velocity, sunshine hours, and pan evaporation, were recorded at the agrometeorological observatory at Tamil Nadu Agricultural University, Coimbatore. The weather conditions that prevailed during the experiment are given in Table 1.

Table 1. Weather conditions prevailing during experiment.

Particulars (Mean)	August 2020–January 2021	August 2021–January 2022
Maximum temperature	29.84 °C	28.21 °C
Minimum temperature	22.32 °C	22.10 °C
Relative humidity	73. 85%	71.89%
Rainfall	722 mm	750 mm
Wind velocity	4.73 mm day^{-1}	4.23 mm day^{-1}

2.3. Soil of the Experiment Field

The initial soil sample was drawn randomly from a depth of around 0–15 cm of the field before sowing, and the resulting soil sample was well air-dried in the drying yard, ground into fine particles, and passed through a 2 mm sieve. The obtained soil sample was then used for analysing the physico-chemical properties, which are presented in Table 2.

Table 2. Physico-chemical characteristics of the soil of the experimental field prior to field experimentation.

Properties	Values
I. Physical properties	
Particle size composition	
Sand (%)	34.50
Silt (%)	17.25
Clay (%)	48.20
Texture	Clay loam
II. Chemical properties	
pH (1:2.5 soil-water suspension)	8.2
EC (dS/m) (1:2.5 soil-water suspension)	0.5
Organic carbon (%)	0.54 (medium)
Available nitrogen (kg/ha)	224 (low)
Available phosphorus (kg/ha)	19.25 (medium)
Available potassium (kg/ha)	571.1 (high)

2.4. Experiment Details

The field experiment aimed to evaluate different intercropping systems involving Bt cotton along with short-duration vegetables compared to sole cotton cultivation (Table 3). The experiment utilised a randomised complete block design with 9 treatments, each replicated thrice. The treatments included various combinations of Bt cotton paired with different intercrops, as well as a control treatment representing sole cotton cultivation.

Table 3. Specifications of the field experiment.

(a)	Statistical Design Used	:	Randomised Block Design
(b)	Number of treatments	:	9
(c)	Number of replications	:	3
(d)	Number of plots (Total)	:	27
(e)	Plot size	:	7.5 m × 4.5 m
(g)	Row spacing	:	60/90 cm × 45 cm
(k)	Recommended NPK dose	:	208:91:99 kg NPK ha^{-1}

The experimental treatments were as follows: (Figure 1)

T_1: Sole Bt Cotton
T_2: Paired Row Planting of Bt Cotton with Two Rows of Intercrop (A)
T_3: Paired Row Planting of Bt Cotton with Two Rows of Intercrop (B)
T_4: Paired Row Planting of Bt Cotton with Two Rows of Intercrop (C)
T_5: Paired Row Planting of Bt Cotton with One Row (A) + One Row (B)
T_6: Paired Row Planting of Bt Cotton with One Row (B) + One Row (C)
T_7: Paired Row Planting of Bt Cotton with One Row (C) + One Row (A)
T_8: Farmers' Practice Bt Cotton + Cowpea
T_9: Recommended Intercropping (Bt Cotton + Blac gram)

In these treatments, intercrops A, B, and C refer to Cluster Bean (*Cyamopsis tetragonoloba*), Beetroot (*Beta vulgaris*), and Coriander (*Coriandrum sativum*), respectively.

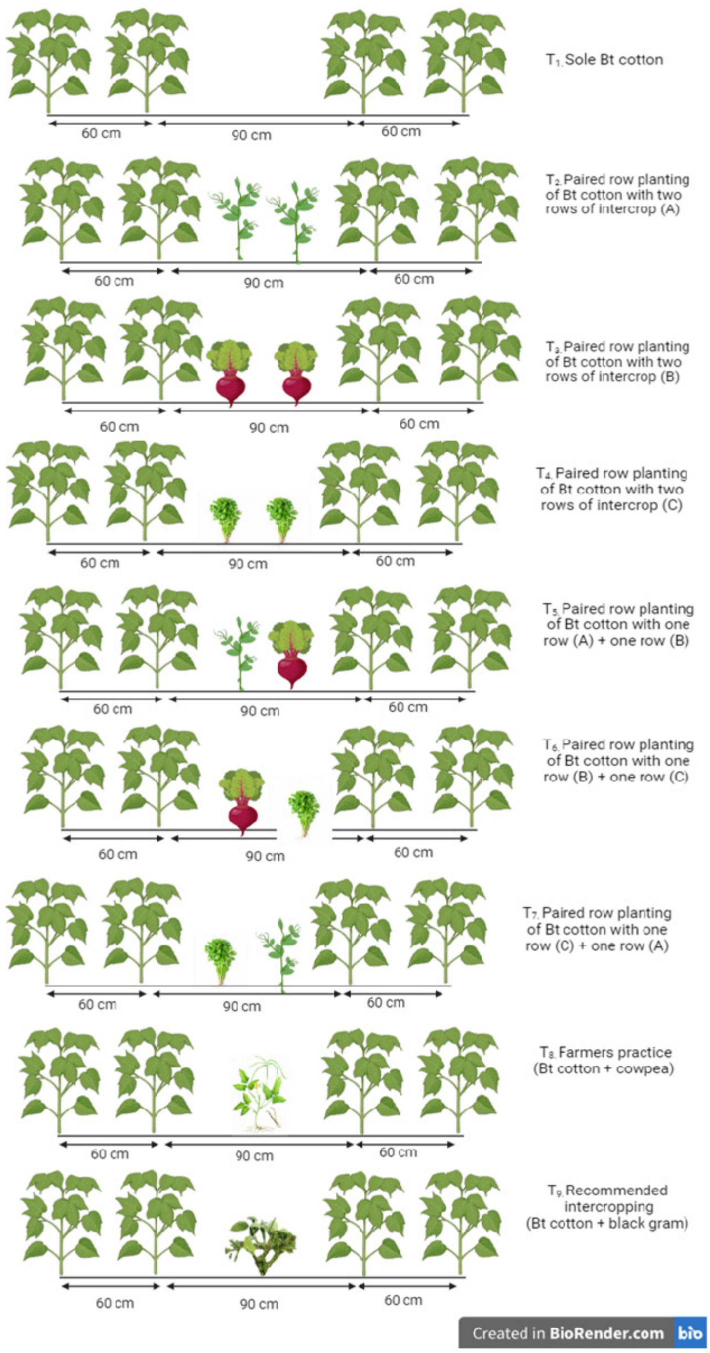

Figure 1. Illustration of the treatment details.

Bt Cotton + Cowpea

This treatment represents the intercropping practice followed by farmers, which involves the cultivation of Bt cotton alongside cowpea (*Vigna unguiculata*).

Recommended Intercropping

This treatment reflects the intercropping system recommended for the optimal yield and resource utilisation, which includes the cultivation of Bt cotton with blackgram (*Vigna mungo*).

The duration of the main crop, as well as that of the intercrops, is presented in Figure 2.

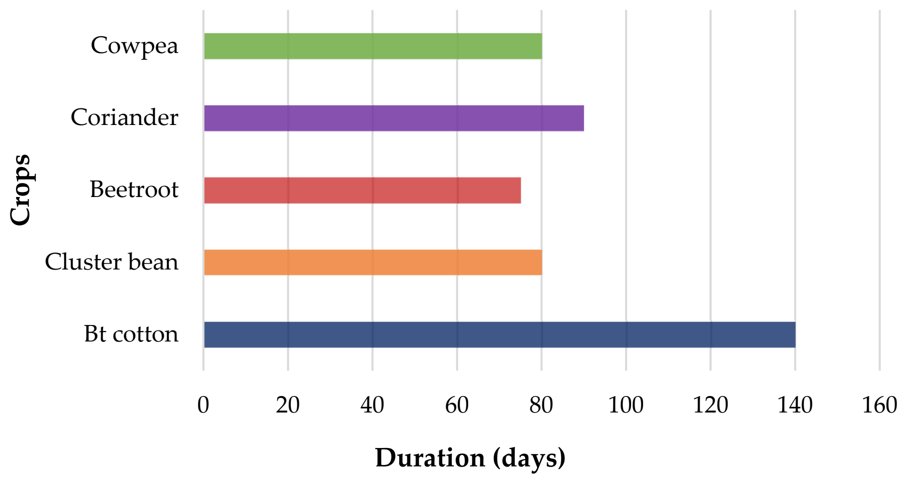

Figure 2. Various crops sown in the field experiment and their duration.

2.5. *Agronomic Management*

In Tamil Nadu, cotton cultivation primarily occurs in two seasons: summer irrigated (February–March) and winter irrigated (August–September). The cultivation process involves several steps to ensure the optimal growth and yield.

2.5.1. Land Preparation

The field was prepared by ploughing once using a tractor-drawn mould-board plough. This initial ploughing was followed by harrowing the field twice to bring the soil to a fine tilth, facilitating better seed germination and root development.

2.5.2. Sowing

Bt cotton Hybrid RCH 625BGII seeds were sown at a depth of 5 cm with spacings of 60/90 × 45 cm. Manual sowing was carried out for all crops, ensuring their proper placement and spacing.

2.5.3. Intercropping

Intercrops, labelled as A, B, and C, were sown simultaneously with the cotton crop. These intercrops were cultivated separately under sole conditions within the same experimental field. This allowed for the calculation of intercropping efficiency indices, which assess the benefits of growing multiple crops together.

2.5.4. Nutrient Management

Primary nutrients such as nitrogen, phosphorus, and potassium were applied to the soil to support the growth of the cotton and intercrops in terms of Urea, Single Super Phosphate, and Murate of Potash. Nitrogen was applied in two equal splits, with the first split applied at the time of planting and the second split at 40 days after sowing (DAS). Phosphorus and potassium were applied as basal fertilisers at the time of sowing to ensure their availability throughout the growing season.

2.5.5. Irrigation

Immediately after sowing, the field was irrigated to facilitate germination. Subsequent irrigation was provided on the 4th day after sowing (DAS). Additional irrigation was scheduled based on the weather conditions and physical appearance of the crops, ensuring that the moisture needs of the plants were met.

2.5.6. Crop Management

Need-based plant protection measures and agronomic practices were carried out as per the Tamil Nadu Agricultural University (TNAU) crop production guide of 2020.

These included pest and disease management, weed control, and other cultural practices to promote healthy crop growth and development.

2.5.7. Harvesting

Harvesting was performed manually in the net plots, and the yields of the various crop used in this study were measured and are expressed in kg ha^{-1}.

2.6. Observations

In the net plot, five plants were randomly selected and tagged. The heights of the five tagged plants were recorded from the ground to the base of last formed leaf and these values were averaged. The total numbers of sympodial branches were counted from the tagged plants. The total number of bolls formed per tagged plant were counted plot wise and their mean value was worked out. At the harvest stage, 10 fully matured and opened representative bolls were collected from each tagged plant, the boll weight was recorded, and then the mean value was estimated. Seed cotton was collected from each net plot, as per the treatments, and the weights of the yields obtained from two pickings were pooled.

2.6.1. Seed Cotton Equivalent Yield (SCEY)

The SCEY was calculated by using the formula,

$$EY = \frac{\sum(\text{Yield of intercrop} \times \text{Price of intercrop})}{\text{Price of seed cotton}}$$

2.6.2. Land Equivalent Ratio (LER)

The LER is the relative land area required to produce the same yield under sole crop conditions as obtained under an intercropping system at the same level of management. This was suggested by [11].

$$LER = \frac{Ya}{Sa} + \frac{Yb}{Sb}$$

where,

Ya and Yb denote the yields of individual crops 'a' and 'b', respectively, in mixture.
Sa and Sb denote the yields of individual crops 'a' and 'b', respectively, in pure stand.

2.6.3. Relative Production Efficiency (RPE)

The RPE was determined by using the following formula and is expressed as a percentage.

$$RPE = \frac{EYD - EYE}{EYE} \times 100$$

where EYD is the equivalent yield under the improved/diversified system and EYE is the yield of the existing system.

2.6.4. Relative Economic Efficiency (REE)

The REE is a comparative measure of the economic gains over the existing system. It is expressed in a percentage.

$$REE = \frac{DNR - ENR}{ENR} \times 100$$

where DNR refers to the net returns obtained under the improved/diversified system and ENR denotes the net returns obtained in the existing system.

2.6.5. Plant Nutrient Analysis

The plant samples were dried and powdered using a Willey mill and were then analysed for N, P, and K, as per the standard procedures.

The plant nutrient uptake was worked out using the following formula.

$$\text{Nutrient uptake} = \frac{\%\ \text{of nutrient in plant} \times \text{DMP}}{100}$$

2.6.6. Economic Analysis

The expenditures for all treatment plots were calculated separately based on the input and market prices prevailing during the course of experimentation. The gross return (Rs. Ha^{-1}), net return (Rs. ha^{-1}), and benefit cost ratio (Rs. ha^{-1}) were calculated based on following formulas.

$$\text{Gross return (Rs. ha}^{-1}) = \text{Economic yield (kg ha}^{-1}) \times \text{Market value (Rs)}$$

$$\text{Net returns (Rs. ha}^{-1}) = \text{Gross return (Rs. ha}^{-1}) - \text{Cost of cultivation (Rs. ha}^{-1})$$

$$\text{Benefit cost ratio} = \text{Gross return/Total cost of cultivation}$$

(Market value for cotton—Rs. 54; Cluster bean—Rs. 35, Beet root—Rs.35; Coriander—Rs. 80; Cowpea—Rs. 70; and Blackgram—Rs. 80)

2.7. Data Analysis

Using the SPSS 16.0 software, an analysis of variance (ANOVA) was conducted, and the differences between the means were compared using Fisher's Least Significant Difference, with a significance level of $p < 0.05$.

3. Results

3.1. Growth Parameters

Plant Height

Upon investigation, plant height varied significantly under the different multi-tier cropping practices at the harvest stage (Table 4). The maximum plant height of Bt cotton (118.9 and 124.0 cm) was observed under T_2, consisting of the paired row planting of Bt cotton with two rows of intercrop (A) followed by the sole planting of Bt cotton (T_1) during both years.

Table 4. Plant height, yield parameter, and seed cotton yield (kg ha^{-1}) as influenced by multi-tier cropping in cotton.

Treatments	Plant Height at Harvest (cm)		No. of Sympodia at Harvest		No. of Bolls m^{-2}		Boll Weight (g)		Seed Cotton Yield (kg ha^{-1})	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T_1	118.3 ab	120.5 ab	20.4 a	24.1 a	47.1	51.2	4.2	4.6	1859 abc	2117 ab
T_2	118.9 a	124.0 a	20.8 a	24.5 a	48.3	52.4	4.3	4.7	2090 a	2148 a
T_3	113.9 abc	116.2 abc	19.9 a	23.6 a	45.4	49.5	4.2	4.6	1702 c	1750 cd
T_4	113.3 abc	118.0 abc	19.7 ab	23.4 a	43.3	47.4	4.2	4.6	1974 ab	2030 abc
T_5	111.1 abcd	113.0 abcd	18.7 ab	22.4 ab	42.1	46.2	4.1	4.5	1650 c	1696 d
T_6	105.0 cd	107.2 cd	18.7 ab	22.4 ab	40.4	44.5	4.1	4.5	1801 bc	1852 bcd
T_7	107.8 bcd	110.2 bcd	18.7 ab	22.4 ab	40.4	44.5	4.1	4.5	1697 c	1744 cd
T_8	99.4 d	102.5 d	16.8 b	20.5 b	37.5	41.6	4.0	4.4	1881 abc	1934 abcd
T_9	100.0 cd	102.1 d	16.9 b	20.6 b	38.3	42.4	4.0	4.4	1754 bc	1804 bcd
SEd	5.6	6.1	1.2	1.0	1.3	1.4	0.2	0.2	122	193
CD (5%)	11.8	12.7	2.5	2.2	NS	NS	NS	NS	257	386

NS: Non-Significant.

3.2. Yield Parameters

The data pertaining to the yield parameters and yield are described in Table 4. The number of sympodia per plant, number of bolls m^{-2}, boll weight, and seed cotton yield were observed and are discussed in the following sub sections.

3.2.1. No. of Sympodia per Plant

During 2021 and 2022, the maximum number of sympodia (20.8 and 24.5) was recorded with the paired row planting of Bt cotton with two rows of cluster bean (T_2), which was on par with the sole planting of Bt cotton (T_1). The minimum number of sympodia (16.8 and 20.9) was recorded with the treatment (T_8) of farmers' practice (Bt cotton intercropped with cowpea).

3.2.2. No. of Bolls m^{-2}

The number of bolls per square metre was not significantly influenced by the different intercropping systems, but there existed a trivial numerical variation in the count of bolls m^{-2}. The maximum number of bolls (48.3 and 52.4) was formed under the treatment with the paired row planting of Bt cotton with two rows of intercrop (A) (A—cluster bean) (T_2), which was almost comparable with T_1 (sole Bt cotton), whereas the minimum number of bolls per square metre was observed with the treatment (T_8) of farmers' practice (Bt cotton intercropped with cowpea).

3.2.3. Boll Weight

The boll weight of the Bt cotton was not significantly influenced by the different multi-tier cropping systems. Nevertheless, there was a slight numerical variation in the boll weight of the Bt cotton, where the intercropping system of Bt cotton with two rows of cluster bean as an intercrop registered the highest boll weights of 4.3 and 4.7 g during the years 2020 and 2021, respectively.

3.2.4. Seed Cotton Yield

The highest seed cotton yields were recorded (2090 and 2148 kg ha^{-1}) with the treatment of Bt cotton intercropped with two rows of cluster bean (T_2) during both seasons. On the contrary, the lowest seed cotton yields of 1650 and 1696 kg ha^{-1} were registered in the intercropping system of Bt cotton with one row of cluster bean (A) and one row of beetroot (B).

3.2.5. Intercrop Yields

The intercrop yields recorded during 2020 and 2021 are shown in Table 5. Among the intercrops, cluster bean recorded higher yields (2400 kg ha^{-1} and 3000 kg ha^{-1}) during 2021 and 2022.

Table 5. Yield of intercrops (kg ha^{-1}) as influenced by multi-tier cropping system of cotton.

Treatments	2020					2021				
	A—Cluster Bean	B—Beetroot	C—Coriander	Cowpea	Blackgram	A—Cluster Bean	B—Beetroot	C—Coriander	Cowpea	Blackgram
T_1	0	0	0			0	0	0		
T_2	2400					3000				
T_3		2000					2220			
T_4			325					378		
T_5	1680	1100				2100	1332			
T_6		1200	138				1332	140		
T_7	1610		180			1610		210		
T_8				560					640	
T_9					400					440

3.3. Efficiency Indices

The efficiency indices calculated during 2020 and 2021 are presented in Table 6. The seed cotton equivalent yield was found to be higher (3645 and 4234 kg ha^{-1} during the years 2020 and 2021, respectively) in the treatment combination of the paired row planting of Bt cotton with two rows of intercrop (A—cluster bean) (T_2). However, the LER was higher (1.87 and 1.95) with the treatment (T_4) where two rows of coriander (C) were intercropped with Bt cotton. The maximum RPE (40% and 45%) was recorded in the treatment (T_2) where two rows of A (A—cluster bean) were intercropped with Bt cotton during both years. Similar to the RPE, the relative economic efficiency was also found to be higher (82% and 86%) with the T_2 treatment, i.e., intercropping two rows of A (A—cluster bean) with Bt cotton. The efficiency indices, viz., LER, RPE, and REE, were inferior for solely Bt cotton (T_1).

Table 6. Efficiency indices as influenced by multi-tier cropping in cotton.

Treatments	Seed Cotton Equivalent Yield (kg ha^{-1})		Land Equivalent Ratio		Relative Production Efficiency (RPE)		Relative Economic Efficiency (REE)	
	2020	2021	2020	2021	2020	2021	2020	2021
T_1	1859	2059	1.00	1.00	−29.0	−29.0	−58.0	−54.0
T_2	3645	4234	1.62	1.70	40.0	45.0	82.0	86.0
T_3	2998	3341	1.04	1.06	15.0	15.0	30.0	27.0
T_4	2456	2734	1.87	1.95	−6.0	−6.0	−12.0	−12.0
T_5	3516	4074	1.31	1.39	35.0	40.0	72.0	75.0
T_6	2846	3176	1.49	1.55	9.0	9.0	19.0	17.0
T_7	3052	3569	1.71	1.83	17.0	23.0	34.0	42.0
T_8	2607	2911	1.45	1.48	0.0	0.0	0.0	0.0
T_9	2347	2606	1.44	1.48	−10.0	−10.0	−21.0	−20.0

3.4. Plant Nutrient Uptake and Post-Harvest Available Nutrients

In the multi-tier cropping system, the uptake of nutrients such as NPK was not significantly influenced in any of the treatment combinations. Similarly, the post-harvest available soil nutrients were also shown to be non-significant (Figures 3 and 4).

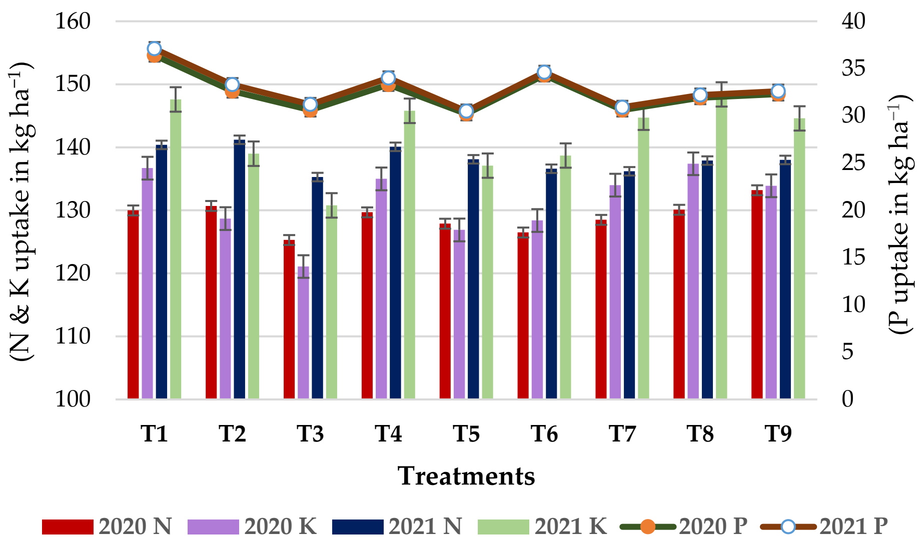

Figure 3. Nutrient uptake as influenced by multi-tier cropping in cotton.

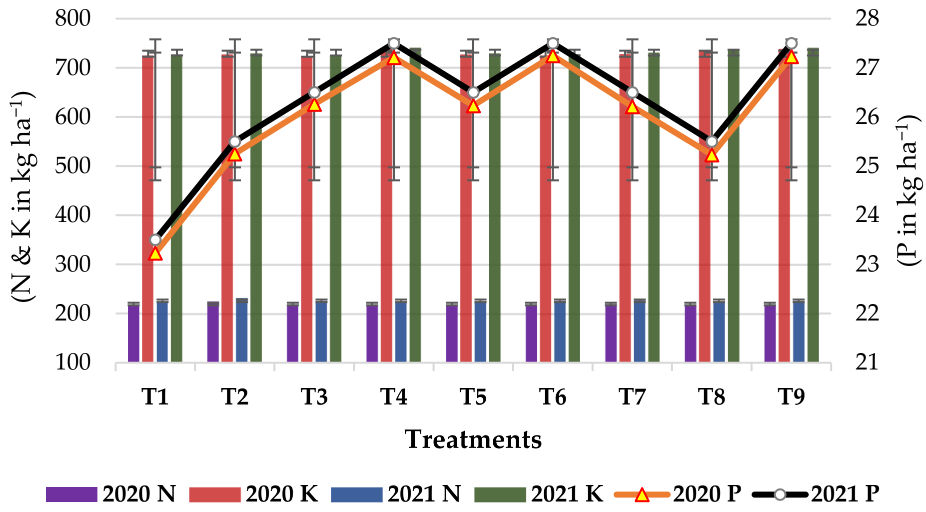

Figure 4. Post-harvest available soil nutrients as influenced by multi-tier cropping in cotton.

3.5. Economics

The economics calculated during 2020 and 2021 are described in Table 7. The highest gross return was recorded (Rs. 196,834 ha^{-1} and Rs. 228,634 ha^{-1}) with the T_2 treatment, i.e., the paired row planting of Bt cotton with two rows of intercrop (A—cluster bean), and the lowest gross return (Rs. 100,391 ha^{-1} and Rs. 111,191 ha^{-1}) was registered in the treatment of solely Bt cotton (T_1) during 2021 and 2022. The maximum net return was recorded (Rs. 123,434 ha^{-1} and Rs. 154,034 ha^{-1}) in the T_2 treatment, i.e., the paired row planting of Bt cotton with two rows of intercrop (A—cluster bean) during both years. The BCR was found to be highest (2.7 and 3.1) with the paired row planting of Bt cotton with two rows of intercrop (A—cluster bean) (T_2) during both years.

Table 7. Economics as influenced by multi-tier cropping in cotton.

Treatments	Treatment Cost (Rs/ha)		Gross Return (Rs/ha)		Net Return (Rs/ha)		BCR	
	2020	2021	2020	2021	2020	2021	2020	2021
T_1	72,000	73,200	100,391	111,191	28,391	37,991	1.4	1.5
T_2	74,400	74,600	196,834	228,634	123,434	154,034	2.7	3.1
T_3	73,050	75,250	161,907	180,407	87,857	105,157	2.2	2.4
T_4	73,140	74,340	132,612	147,652	59,472	73,312	1.8	2.0
T_5	73,710	74,910	189,879	219,999	116,169	145,089	2.6	2.9
T_6	73,074	74,274	153,680	171,500	80,606	97,226	2.1	2.3
T_7	73,764	74,964	164,824	192,724	91,060	117,760	2.2	2.6
T_8	73,050	74,250	140,775	157,175	67,725	82,925	1.9	2.1
T_9	73,050	74,250	126,735	140,735	53,685	66,485	1.7	1.9

4. Discussion

Various cropping systems, viz., sole cropping and the intercropping of Bt cotton with component crops, significantly influenced the growth of Bt cotton. The paired row planting of Bt cotton with two rows of cluster bean as an intercrop significantly registered the maximum plant height due to the competition effect of the intercrop for its requirements like sunlight, space, and water, etc., thus generating pressure on the main crop (Bt cotton) and thereby resulting in taller plants. A similar finding was noticed in the study conducted by [12,13].

Regarding the yield attributes of Bt cotton, the number of sympodia plants^{-1} was significantly higher in the cropping system of the paired row planting of Bt cotton with two rows of cluster bean (intercrop), but was equally comparable with the sole cropping of Bt cotton. Usually, with the sole cropping of cotton, there is no competition for resources, thus meaning the crop develops more reproductive branches. But in the case of intercropping, the inclusion of intercrops by altering the crop geometry causes some competitive effects on the main crop, but the proper selection of intercrops conferring minimum or negligible competition to the main crop can be conducted so as to create a mutualistic relationship between these crops. This finding was consistent with the finding of [14]). Equally, the counts of bolls m^{-2} and boll weight were numerically higher in the cropping system involving the paired row planting of Bt cotton with two rows of cluster bean as an intercrop. The intercrop cluster bean was harvested at around 75 to 80 DAS, thus completely avoiding the competition effect of intercropping and subsequently favouring boll formation, a high number of bolls, and a greater boll weight. The present findings corroborate the findings of [15].

With regard to the seed cotton yield of Bt cotton, the cropping system of the paired row planting of Bt cotton with two rows of cluster bean statistically registered a superior seed cotton yield when compared to the other cropping systems involved in the study. This increment in the seed cotton yield of Bt cotton was due to the harvesting of cluster bean during the commencement of the reproductive stage of the Bt cotton, thus ensuring zero competition from the intercrop and thereby facilitating the enhanced production of yield attributes, viz., the number of sympodial branches, count of bolls, and boll weight, ultimately resulting in the maximum seed cotton yield. The outcome of this experiment is in line with the findings of [16].

The seed cotton equivalent yield was higher in the intercropping system of the paired row planting of Bt cotton with two rows of cluster bean. This was because these two crops produced superior yields and also fetched better market price. Regarding economics, the maximum gross returns, net returns, and BC ratio were recorded in the paired row planting of Bt cotton with two rows of cluster bean. As the seed cotton yield and seed cotton equivalent yield were improved in the intercropping system of the paired row planting of Bt cotton with two rows of cluster bean, subsequently, the returns were also maximised when adopting this practice of intercropping. Similar findings were observed in the study of [14,16].

The RPE and REE were higher in the paired row planting system of Bt cotton with two rows of cluster bean as an intercrop, since the yield and net returns attained from the Bt cotton and intercrop (cluster bean) under this cropping system were high when compared with the existing production system. In [16], similar results were also observed with regard to the RPE and REE under various intercropping systems. Regarding the land equivalent ratio (LER), the paired row planting of Bt cotton with two rows of coriander registered the maximum LER. A higher or positive LER specifies that the intercropping system is highly beneficial compared to that of sole cropping. Numerous intercropping systems involving cotton as the main crop have recorded positive LERs, as evidenced by [12,17–19].

Nitrogen, phosphorus, and potassium were at maximum in the paired row planting of Bt cotton with one row of cluster bean and one row of beetroot. The uptake of nutrients was greater in the paired row planting system of Bt cotton + one row of cluster bean and one row of beetroot because of the varied root growth patterns exhibited by the intercrops, which effectively utilised the available nutrients in the soil, thereby contributing to a higher yield. A similar pattern of nutrient uptake was noticed by [16] in a multi-tier cropping system.

5. Conclusions

Upon comparing sole cropping with the adoption of a paired row system of planting Bt cotton with two rows of cluster bean, the latter proved to be highly remunerative in all aspects of crop production. So, the adoption of a paired row system of cropping with suitable intercrops promoted a cotton equivalent yield and additional revenue, and these synergistic effects to the main crop were realised through the effective utilisation of available resources, viz., land, labour, and time.

Author Contributions: K.T., designed the concept and methodology; K.T., K.N., N.V. and V.S. (Vaddi Saitheja), writing and original draft preparation; K.T., K.N., N.V., V.M., G.P., P.P., M.K.K., R.K. and V.S. (Vaddi Saitheja), review and editing; K.T., K.N., V.S. (Vaddi Saitheja), G.P., P.P., M.K.K., R.K. and V.S. (Vaithiyanathan Sendhilvel), Supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data used and presented in this paper are available upon request from the corresponding author.

Acknowledgments: The authors express special heartfelt thanks to CICR, Regional Staion, Coimbatore., Department of Cotton and Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, for their valuable support and suggestions during the course of study.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Blaise, D.; Kranthi, K. Cotton production in India. In *Cotton Production*; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2019; ch10, pp. 193–215. [CrossRef]
2. Gandhi, V.P.; Jain, D.; Gandhi, V.P.; Jain, D. Introduction and Objectives of the Study. In *Introduction of Biotechnology in India's Agriculture: Impact, Performance and Economics*; Springer: Singapore, 2016; pp. 3–5.
3. Reddy, K.A.; Reddy, K.R.; Reddy, M.D. Effects of intercropping on yield and returns in corn and sorghum. *Exp. Agric.* **1980**, *16*, 179–184. [CrossRef]
4. Maitra, S.; Ray, D.P. Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems: A Review. *Int. J. Bioresour. Sci.* **2019**, *6*, 11–19. [CrossRef]
5. Gitari, H.I.; Nyawade, S.O.; Kamau, S.; Karanja, N.N.; Gachene, C.K.; Raza, M.A.; Maitra, S.; Schulte-Geldermann, E. Revisiting intercropping indices with respect to potato-legume intercropping systems. *Field Crops Res.* **2020**, *258*, 107957. [CrossRef]
6. Maitra, S.; Gitari, H. Scope for adoption of intercropping system in organic agriculture. *Indian J. Nat. Sci.* **2020**, *11*, 28624–28631.
7. Nyawade, S.; Gitari, H.I.; Karanja, N.N.; Gachene, C.K.; Schulte-Geldermann, E.; Sharma, K.; Parker, M.L. Enhancing climate resilience of rain-fed potato through legume intercropping and silicon application. *Front. Sustain. Food Syst.* **2020**, *4*, 566345. [CrossRef]
8. Khan, M.B.; Khan, M.; Hussain, M.; Farooq, M.; Jabran, K.; Lee, D.J. Bio-economic assessment of different wheat-canola intercropping systems. *Int. J. Agric. Biol.* **2012**, *14*, 769–774.
9. Saeed, M.; Shahid, M.; Jabbar, A.; Ullah, E.; Bismillah, M. Agro-economic assessment of different cotton-based inter/relay cropping systems in two geometrical patterns. *Int. J. Agric. Biol.* **1999**, *4*, 234–237.
10. Gadade, G.; Blaise, D.; Rao, M. Intercropping in cotton in India-a review. *J. Cotton Res. Dev.* **2006**, *20*, 58–63.
11. Willey, R.W. Intercropping-its importance and its research needs. Part I. Competition and yield advantages. *Field Crop Abstr.* **1979**, *32*, 1–10.
12. Kumar, R.; Turkhede, A.; Nagar, R.; Nath, A. Effect of different intercrops on growth and yield attributes of American cotton under dry land condition. *Int. J. Curr. Microbiol. Appl. Sci.* **2017**, *6*, 754–761.
13. Kumar, S.; Turkhede, A.; Wankhede, R.; Meena, A.K. Growth, yield and quality of cotton in cotton based intercropping system under organic and rainfed condition. *Pharma Innov. J.* **2022**, *11*, 154–157.
14. Aladakatti, Y.; Hallikeri, S.; Nandagavi, R.; Hugar, A.; Naveen, N. Effect of intercropping of oilseed crops on growth, yield and economics of cotton (Gossypium hirsutum) under rainfed conditions. *Karnataka J. Agric. Sci.* **2011**, *24*, 280–282.
15. Sankaranarayanan, K.; Nalayini, P.; Sabesh, M.; Rajendran, K.; Nachane, R.; Gopalakrishnan, N. *Multi-Tier Cropping System Foprofitability and Stability in Bt Cotton Production*; Technical Bulletin No 2; Central Institute for Cotton Research, Regional Station: Coimbatore, India, 2011. Available online: https://krishi.icar.gov.in/jspui/bitstream/123456789/3803/1/CICR_multitier.pdf (accessed on 8 May 2024).
16. Sankaranarayanan, K.; Nalayini, P.; Praharaj, C. Multi-tier cropping system to enhance resource utilization, profitablity and sustainablity of Bt cotton (*Gossypium hirsutum*) production system. *Indian J. Agric. Sci.* **2012**, *82*, 1044–1050. [CrossRef]
17. Aasim, M. Yield and competition indices of intercropping cotton (*Gossypium hirsutum* L.) using different planting patterns. *J. Agric. Sci.* **2008**, *14*, 326–333.
18. Yadav, G.S.; Shivay, Y.; Kumar, D.; Babu, S. Enhancing iron density and uptake in grain and straw of aerobic rice through mulching and rhizo-foliar fertilization of iron. *Afr. J. Agric. Res.* **2013**, *8*, 5447–5454.
19. Rajpoot, S.K.; Rana, D.; Choudhary, A.K. Bt-cotton–vegetable-based intercropping systems as influenced by crop establishment method and planting geometry of Bt-cotton in Indo-Gangetic plains region. *Curr. Sci.* **2018**, *115*, 516–522. [CrossRef]