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Megharani
Department of Agronomy, University of Agricultural Sciences, Raichur, Karnataka, India

Vilaskumar
College of forestry, University of Agricultural Sciences, Dharwad, Karnataka, India

Gururaj
College of Agriculture, Kalaburagi, University of Agricultural Sciences, Raichur, Karnataka, India

Rathod PS
College of Agriculture, Kalaburagi, University of Agricultural Sciences, Raichur, Karnataka, India

Corresponding Author:
Megharani
Department of Agronomy, University of Agricultural Sciences, Raichur, Karnataka, India

Growth, yield and economics of inter crops in pigeon pea as influenced by irrigation and cropping system under drip irrigation

Megharani, Vilaskumar, Gururaj and Rathod PS

Abstract
A field experiment was conducted at Zonal Agricultural Research Station, Kalaburagi, during the kharif season of 2018-19 to investigate the "Growth, yield and economics of intercrops in pigeon pea as influenced by irrigation levels and cropping systems under drip irrigation". The experiment employed a split-plot design with three main factors of irrigation levels and four sub-factors of cropping systems, replicated thrice. The results indicated significantly higher growth attributes, including a plant height of 43.53 cm, 3.92 branches per plant, leaf area of 14.93 dm^2 per plant, LAI of 4.98, and TDMP of 32.13 g per plant at harvest. Furthermore, yield attributes such as 15.28 pods per plant, pod weight of 11.93 g per plant, seed yield of 4.86 g per plant, grain yield of 1575 kg per ha, and haulm yield of 6416 kg per ha were also recorded. The experiment showed that a 75% Crop Water Requirement (CPE) ratio outperformed both 50% and 100% CPE ratios, demonstrating higher gross returns (Rs. 226245 per ha), net returns (Rs. 173435 per ha), and a Benefit-Cost (BC) ratio of 4.29. Among the cropping systems studied, pigeon pea + green gram (1:3) exhibited superior performance, with higher plant height (49.29 cm), leaf area (15.37 dm^2 per plant), LAI (5.12), TDMP (34.47 g per plant), gross returns (Rs. 252400 per ha), net returns (Rs. 196590 per ha), and a BC ratio of 4.52 compared to pigeon pea + black gram and pigeon pea + soybean.

Keywords: CPE, plant height, LAI, TDMP, grain yield and stalk yield

Introduction
Pulses, such as pigeon pea (*Cajanus Cajan* L. Mill sp.), are commonly cultivated as rain fed crops across the Indian plains during the monsoon season. Pigeon pea, in particular, is predominantly grown for its processed pulse, known as dhal, within diverse cropping systems that include both inters and mixed cropping. In India, the growing human population and the need to address malnutrition have led to an escalating demand for pulses and oilseeds, in addition to cereals. Despite this demand, the per capita availability of pulses has decreased from 69 grams in 1961 to approximately 37.8 grams in 2001, falling below the WHO/FAO recommendation of 80 grams per day. Bridging this nutritional gap is crucial, and there is a pressing need to enhance pulse production. However, expanding the cultivation area has limitations. The solution lies in increasing productivity, and adopting effective agronomic practices, particularly intercropping systems, emerges as one of the most promising approaches to meet the rising demand.
Intercropping pigeon pea with crops such as greengram (*Vigna radiata*), blackgram [*Vigna mungo* (L.) Hepper], and soybean (*Glycine max*) proves to be a viable strategy without significantly compromising the yield of the main crop. Pigeon pea, characterized by its late maturation, tall stature, and wide spacing with a deep root system, is well-suited for intercropping systems. Additionally, the gradual growth of pigeon pea in its early stages provides an opportune window for intercropping with more rapidly growing, shorter-duration crops like green gram, black gram, soybean, as well as taller crops such as pearl millet and sesamum. This approach optimally utilizes natural resources during the initial phases of pigeon pea growth.

Material and Methods
In the kharif season of 2018-19, a field experiment took place at the Zonal Agricultural Research Station in Kalaburgi, located in the North Eastern Dry Zone of Karnataka at coordinates 17° 34' North latitude and 76° 79' East longitude, with an altitude of 478 meters above mean sea level (MSL). The experimental layout followed a split plot design,

incorporating three main factors of irrigation levels (I_1: 50% CPE, I_2: 75% CPE, and I_3: 100% CPE) and four sub-factors of cropping systems (C_1: Sole pigeon pea, C2: Pigeon pea + Green gram, C3: Pigeon pea + Black gram, and C4: Pigeon pea + Soybean). The experiment was replicated thrice, with Rain fed pigeon pea serving as the control. The recommended fertilizer dose for pigeon pea (25:50:0 kg N: P2O5: K2O) was applied at the time of sowing, utilizing diammonium phosphate (DAP) for nitrogen, phosphorus, and potassium. Additionally, farmyard manure (FYM) at a rate of 6 t ha-1 was incorporated into the soil two weeks before sowing. Subsequently, water-soluble fertilizers, including 4 kg of 19:19:19 (N: P: K) and 8.5 kg of MAP (12:61:0), were applied through drip irrigation throughout the crop's growth period. Sowing was initiated on June 13, 2018, with the total rainfall recorded during the season amounting to 549.81 mm.

The experimental site's soil was characterized as black clay, exhibiting a slight alkaline nature with a pH of 8.20 and an electrical conductivity of 0.23 dS m^{-1}. The soil's organic carbon content was relatively low, measuring at 0.52%. In terms of nutrient levels, the soil showed a deficiency in available nitrogen (235 kg $ha^{-1)}$, a medium availability of phosphorus (32 kg ha^{-1}), and a high concentration of available potassium (460 kg ha^{-1}). To address these soil conditions, fertilizer application was implemented, with soil fertilization carried out at 30 days after sowing (DAS) and foliar fertilization administered at the 50% flowering stage

Results and Discussion

Growth parameters of intercrops: The growth parameters of pigeon pea when intercropped with green gram, black gram, and soybean were examined in relation to drip irrigation scheduling and cropping systems. The data presented in Table 1 revealed that irrigation scheduled at 75% Crop Water Requirement (CPE) resulted in a taller plant height, measuring 43.53 cm. This outcome was attributed to the consistent moisture supply throughout the entire crop growth period, fostering improved growth and development, and subsequently, increased plant height. Similar findings were reported by Patel *et al*. (2007) [12] for cluster bean and Patel *et al*. (2016) [11] for green gram. Moreover, there was an increase in the number of branches per plant (3.92), potentially linked to the maintenance of higher plant water status and a cooler canopy. This condition facilitated enhanced absorption of photo synthetically active radiation and a higher rate of photosynthesis, aligning with the results observed by Kavitha and Wahab (2001) [4]. The intercropped plants at 75% CPE also exhibited higher leaf area (14.93 dm2 $plant^{-1}$) and leaf area index (4.98). This acceleration in vegetative growth led to the development of an extensive photosynthetic apparatus and a relative increase in leaf area, a phenomenon in line with the findings of Elamathi and Singh (2001) [2] in soybean. Furthermore, total dry matter production was notably higher at 32.13 g $plant^{-1}$ under 75% CPE. This increase could be attributed to the greater availability of essential nutrients under optimum conditions, resulting in a balanced nourishment of plants. The outcome manifested in the formation of taller, thicker stems, and root systems, ultimately contributing to an increased dry weight compared to instances with 50% and 100% CPE.

Within various intercropping systems, pigeon pea intercropped with green gram exhibited superior performance, showcasing higher plant height (49.29 cm), leaf area (15.37 dm2 plant-1), leaf area index (5.12), and total dry matter production (34.47 g plant-1) compared to intercropping with black gram and soybean. However, in terms of branches per plant in the intercrops, pigeon pea intercropped with soybean recorded a higher number of branches (4.12) compared to its counterparts with green gram and black gram. This observed difference can be attributed to the competitive nature of pigeon pea intercropped with soybean, demonstrating a greater ability to compete for essential growth resources such as light, moisture, nutrients, and space, particularly with an increase in plant density. These findings align with the results reported by Pal *et al*. (2016) [10] and Tomar *et al*. (1984) [15].

The interaction effect between irrigation scheduling and cropping systems had a noteworthy impact on various growth parameters. Specifically, when irrigation was scheduled at 75% Crop Water Requirement (CPE) and pigeon pea was intercropped with green gram, there was a considerable increase in plant height (53.73 cm), leaf area (16.60 dm2 plant-1), leaf area index (5.53), and total dry matter production (37.26 g plant-1). Contrastingly, in terms of the number of branches per plant, the combination of irrigation scheduled at 75% CPE with soybean intercropping recorded a significantly higher number of branches (4.63) compared to other combinations. This difference can be attributed to the distinct influence of irrigation scheduling and cropping systems on the competitive dynamics for growth resources, showcasing a nuanced interplay between these factors in shaping the observed outcomes.

Yield parameters of intercrops: Table 2 presents data on yield parameters for pigeon pea intercropped with green gram, black gram, and soybean, considering the influence of drip irrigation scheduling and cropping systems.

Significantly higher yield parameters were observed when irrigation was scheduled at 75% Crop Water Requirement (CPE). This included a higher number of pods per plant (15.28), greater pod weight per plant (11.93 g), increased seed yield per plant (4.86 g), and elevated grain yield (1575 kg ha^{-1}) and haulm yield (6416 kg per hectare) compared to irrigation scheduled at 50% CPE and 100% CPE. The enhanced yield at 75% CPE was attributed to the consistent water supply, leading to increased water uptake, an extended reproductive phase, and a larger photosynthetic green surface. These conditions provided optimal reproductive storage capacity, resulting in a higher allocation of dry matter to the seed. The progressive increase in yield was facilitated by favorable soil moisture conditions and improved availability of soil moisture with higher irrigation frequency throughout the crop growth period. This finding aligns closely with the results reported by Idnani and Gautam (2008) [3] and Yadav and Singh (2014) [16]. Kumar *et al*. (2015) [5] additionally highlighted that an irrigation application at a 0.8 Irrigation Water to Crop Water Requirement (IW/CPE) ratio yielded the highest seed yield (1489 kg per hectare) compared to other treatments. However, no significant differences were observed among treatments in terms of test weight and harvest index, as reported by Kumar *et al.* (2015) [5].

Among the intercrops, soybean recorded significantly higher pod weight per plant (12.94 g), seed yield per plant (5.23 g $plant^{-1}$), grain yield (1732 kg ha^{-1}) and haulm yield (8012 kg ha^{-1}) than black gram and green gram. This might be due to optimum plant population which effectively utilizes all the resources for making favorable conditions to get higher yield components reducing the competition. The results are conformity with the finding of Rekha and Dhurua (2009) [13]

and Sarma *et al*. (2016) [14]. And also soybean recorded higher test weight (123.26 g) difference in test weight are mainly due to genetic character of the variety and difference in weight of seeds in green gram, black gram and soybean. But number of pods per plant did not showed any difference. Significantly higher harvest index was recorded by black gram (26.38%) this might be due to increased economical yield and lower biological yield compared to green gram and soybean thereby recorded higher harvest index in black gram.

Scheduling of irrigation at 75% CPE with black gram recorded significantly higher number of pods (17.50) and harvest index (27.45%) as compared to rest of the treatment combinations. But in case of pod weight (14.21 g plant^{-1}), seed yield (5.65 g plant^{-1}), test weight (124.36 g), grain yield (1885 kg ha^{-1}) and haulm yield (9312 kg ha^{-1}) recorded significantly higher at scheduling of irrigation at 75% CPE with soybean as compared to other treatments.

Pigeon pea equivalent yield: The pigeon pea equivalent yield exhibited a significant increase at 75% Crop Water Requirement (CPE), reaching 3771 kg ha^{-1}, in contrast to both 50% CPE and 100% CPE. Conversely, a notably lower pigeon pea equivalent yield of 3267 kg ha^{-1} was recorded at 50% CPE.

Furthermore, the highest pigeon pea equivalent yield was achieved when pigeon pea was intercropped with green gram, reaching 4207 kg ha^{-1}, surpassing all other cropping systems. This superior yield was attributed to the higher yields of both pigeon pea and intercrops, coupled with a favorable market price. These outcomes align with previous studies conducted by Rathod *et al*. (2004) [9], Malik *et al*. (2013) [6], and Nandhini and Latha (2014) [8], supporting the consistency of the current findings of the study.

Economics of inter crops: The economic analysis of pigeon pea, considering irrigation levels and cropping systems under drip irrigation, is presented in Table 3. The data revealed that the cost of cultivation was lower at 50% Crop Water Requirement (CPE), amounting to Rs. 52,310 per hectare. However, irrigation scheduling at 75% CPE, equivalent to 100% CPE, resulted in higher gross returns (Rs. 226,245 per hectare), net returns (Rs. 173,435 per hectare), and a Benefit-Cost (B: C) ratio of 4.29. This parity with 100% CPE indicates that the optimal irrigation scheduling at 75% CPE led to comparable economic returns, likely attributed to the higher yields recorded under this irrigation regime. These findings align with similar results reported by Muniyappa *et al*. (2017) [7] in chickpea, and Deewan *et al*. (2017) [1] in cluster bean.

The data presented in Table 3 indicates a lower cost of cultivation at Rs. 38,560 per hectare in sole pigeon pea cultivation. However, in the case of pigeon pea intercropped with green gram in a 1:3 row proportion, significantly higher gross returns (Rs. 2,52,400 per hectare), net returns (Rs. 1,96,590 per hectare), and a Benefit-Cost (BC) ratio of 4.52 were recorded compared to sole pigeon pea, as well as intercropping with black gram and soybean. This observed increase in returns can be attributed to the higher yields of both pigeon pea and green gram, coupled with the favorable market prices for both crops, resulting in increased overall profit.

Furthermore, the interaction effect between irrigation scheduling and cropping systems on gross returns (Rs. 2,67,960 per hectare), net returns (Rs. 2,12,150 per hectare), and a BC ratio of 4.80 for pigeon pea was significantly higher when irrigation was scheduled at 75% Crop Water Requirement (CPE) in the pigeon pea + green gram (1:3) intercropping system. This finding suggests that the higher yields obtained in this treatment, in comparison to others, contributed to the overall increase in returns.

The pigeon pea cultivated under rain fed conditions exhibited notably lower gross returns at Rs. 66,880 per hectare, along with reduced net returns amounting to Rs. 36,518 per hectare and a Benefit-Cost (BC) ratio of 2.20.

Table 1: Growth parameters of intercrops as influenced by irrigation levels and cropping systems under drip irrigation

Treatments	Plant height (cm)	Number of primary branches per plant	Leaf area (dm2/plant)	Leaf area index	Total dry mater production (g/plant)
Main plot: Irrigation levels (I)					
50% CPE (I_1)	39.27	3.21	13.22	4.41	26.64
75% CPE (I_2)	43.53	3.92	14.93	4.98	32.13
100% CPE (I_3)	39.93	3.31	14.21	4.74	29.85
S.Em±	0.72	0.08	0.23	0.08	0.67
C.D. at 5%	2.82	0.31	0.90	0.30	2.63
Sub plot: Cropping systems (C)					
Greengram (C_1)	49.29	3.14	15.37	5.12	34.47
Blackgram (C_2)	42.62	3.18	11.90	3.97	32.47
Soybean (C_3)	30.82	4.12	15.10	5.03	21.68
S.Em±	1.06	0.27	0.37	0.12	1.00
C.D. at 5%	3.27	0.82	1.13	0.38	3.09
Interaction effects (I x C)					
50% CPE x Greengram (I_1 x C_1)	46.47	2.70	14.59	4.86	31.72
50% CPE x Blackgram (I_1 x C_2)	41.60	2.67	11.06	3.69	28.57
50% CPE x Soybean (I_1 x C_3)	29.73	4.27	14.01	4.67	19.62
75% CPE x Greengram (I_2 x C_1)	53.73	3.67	16.60	5.53	37.26
75% CPE x Blackgram (I_2 x C_2)	43.33	3.47	12.45	4.15	34.74
75% CPE x Soybean (I_2 x C_3)	32.53	4.63	15.75	5.25	24.39
100% CPE x Greengram (I_3 x C_1)	47.67	3.07	14.91	4.97	34.41
100% CPE x Blackgram (I_3 x C_2)	41.93	3.40	12.18	4.06	34.11
100% CPE x Soybean (I_3 x C_3)	30.20	3.47	15.54	5.18	21.02
S.Em±	1.84	0.46	0.63	0.21	1.73
C.D. at 5%	5.66	1.35	1.95	0.65	5.34

Table 2: Yield and yield parameters of intercrops as influenced by irrigation levels and cropping systems under drip irrigation

Treatments	Number of pods per plant	Pod weight per plant (g)	Seed yield per plant (g)	1000 seed weight (g)	Grain yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index (%)
Main plots: Irrigation levels (I)							
50% CPE (I_1)	11.46	9.38	3.91	72.87	1277	5172	20.63
75% CPE (I_2)	15.28	11.93	4.86	74.98	1575	6416	21.89
100% CPE (I_3)	14.06	11.02	4.52	73.64	1488	5830	21.52
S.Em±	0.70	0.26	0.10	1.89	19	209.46	0.45
C.D. at 5%	2.74	1.04	0.40	NS	75	822.43	NS
Sub plot: Cropping systems (C)							
Greengram (C_1)	12.84	10.88	4.43	47.97	1427	6096	19.80
Blackgram (C_2)	13.93	8.50	3.63	50.55	1182	3310	26.38
Soybean (C_3)	14.03	12.94	5.23	123.26	1732	8012	17.86
S.Em±	0.67	0.30	0.11	1.73	40	236.99	0.49
C.D. at 5%	NS	0.91	0.35	5.32	125	730.23	1.51
Interaction effects (I x C)							
50% CPE x Greengram (I_1 x C_1)	12.53	9.35	3.95	46.35	1250	5471	18.90
50% CPE x Blackgram (I_1 x C_2)	9.50	7.25	2.95	50.07	1020	3198	24.44
50% CPE x Soybean (I_1 x C_3)	12.36	11.53	4.83	122.18	1560	6848	18.55
75% CPE x Greengram (I_2 x C_1)	13.20	12.41	4.89	49.35	1550	6505	21.39
75% CPE x Blackgram (I_2 x C_2)	17.50	9.17	4.03	51.23	1290	3430	27.45
75% CPE x Soybean (I_2 x C_3)	15.13	14.21	5.65	124.36	1885	9312	16.84
100% CPE x Greengram (I_3 x C_1)	12.80	10.89	4.44	48.21	1480	6313	19.11
100% CPE x Blackgram (I_3 x C_2)	14.80	9.08	3.90	50.36	1235	3302	27.26
100% CPE x Soybean (I_3 x C_3)	14.59	13.08	5.23	123.25	1750	7875	18.18
S.Em±	1.17	0.51	0.19	2.99	61	410	0.85
C.D. at 5%	3.59	1.58	0.60	9.22	190	1265	2.62

Table 3: Pigeon pea yield, pigeon pea equivalent yield, gross returns, cost of cultivation, net returns and B:C ratio as influenced by irrigation levels and cropping systems under drip irrigation

Treatments	Grain yield of pigeon pea (kg ha^{-1})	Pigeon pea equivalent yield (kg/ha)	Gross returns (Rs./ha)	Cost of cultivation (Rs./ha)	Net returns (Rs./ha)	B:C Ratio
Main plots: Irrigation levels (I)						
50% CPE (I_1)	2276	3267	196020	52310	143710	3.77
75% CPE (I_2)	2524	3771	226245	52810	173435	4.29
100% CPE (I_3)	2462	3634	218010	53310	164700	4.10
S.Em±	37	55	4630	-	4630	0.08
C D at 5%	146	215	18210	-	18210	0.30
Sub plot: Cropping systems (C)						
Sole pigeon pea (C_1)	2656	2656	159380	38560	120820	4.13
Pigeon pea + Greengram (C_2)	2304	4207	252400	55810	196590	4.52
Pigeon pea + Blackgram (C_3)	2358	3845	230700	58060	172640	3.97
Pigeon pea + Soybean (C_4)	2366	3520	211220	58810	152410	3.59
S.Em±	58	73	5850	-	5850	0.12
C D at 5%	170	218	17390	-	17390	0.40
Interaction effects (I x C)						
50% CPE x Sole pigeon pea (I_1 x C_1)	2501	2501	150060	38060	112000	3.94
50% CPE x Pigeon pea + Greengram (I_1 x C_2)	2171	3838	230280	55310	174970	4.16
50% CPE x Pigepnpea + Blackgram (I_1 x C_3)	2216	3471	208260	57560	150700	3.62
50% CPE x Pigepnpea + Soybean (I_1 x C_4)	2218	3258	195480	58310	137170	3.35
75% CPE x Sole pigeon pea (I_2 x C_1)	2750	2750	165000	38560	126440	4.28
75% CPE x Pigeon pea + Greengram (I_2 x C_2)	2399	4466	267960	55810	212150	4.80
75% CPE x Pigepnpea + Blackgram (I_2 x C_3)	2449	4112	246720	58060	188660	4.25
75% CPE x Pigepnpea + Soybean (I_2 x C_4)	2498	3755	225300	58810	166490	3.83
100% CPE x Sole pigeon pea (I_3 x C_1)	2718	2718	163080	39060	124020	4.18
100% CPE x Pigeon pea + Greengram (I_3 xC_2)	2343	4316	258960	56310	202650	4.60
100% CPE x Pigepnpea + Blackgram (I_3 xC_3)	2408	3952	237120	58560	178560	4.05
100% CPE x Pigepnpea + Soybean (I_3 x C_4)	2381	3548	212880	59310	153570	3.59
S.Em±	95	123	9930	-	9930	0.22
C D at 5%	280	365	29500	-	29500	0.65
Rainfed pigeon pea	1080	1080	66880	30362	36518	2.20

Conclusion

Based on the findings of the study, it can be deduced that the irrigation scheduling at 75% Crop Water Requirement (CPE) in the pigeon pea + green gram (1:3) intercropping system proved to be the most profitable. This system recorded significantly higher net returns and a superior benefit-cost ratio compared to other irrigation scheduling and cropping systems.

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