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Crop Establishment Techniques under Altered Crop Geometries for Higher Productivity of Rice - Vegetable Cowpea Cropping System

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Field experiment was conducted during *rabi* season, 2013-14 to the study the effect of crop establishment techniques and crop geometries on growth attributes, water productivity and yield of rice-vegetable cowpea cropping system. Experiment was laid out in strip plot design and treatments were replicated thrice. The sixteen treatment combinations consisted of four establishment techniques *viz.,* puddled transplanting (E_1), puddled direct seeding (E_2), unpuddled transplanting (E_3), unpuddled direct seeding (E_4) and four crop geometries such as 30 cm x 20 cm (S_1), 20 cm x 10 cm (S_1), 25 cm x 25 cm (S_3) and 30 cm x 30 cm (S_4). Among the different treatment combinations, square planting of 25 cm x 25 cm was adopted in puddled condition resulted in higher grain yield of 6963 kg ha^{-1} and straw yield of 9299 kg ha^{-1}. Higher number of tillers m^{-2} (416.4), productive tillers m^{-2} (389.4), days to 50% panicle initiation (76), effective tiller percentage (96.6) and filled grains panicle^{-1} (275.1) were registered in same treatment combination. However, higher water productivity of 4.56 kg ha mm^{-1}, establishment index (0.98) and root shoot ratio (0.45) were obtained in unpuddled direct seeding with 30 cm x 30 cm spacing. In case of succeeding vegetable cowpea, higher yield of 8780 kg ha^{-1}, harvest index (0.57), water productivity (14.16 kg ha mm^{-1}), emergence index (0.97) and days to 50% flowering (45.7) were recorded in 30 cm x 30 cm spacing under unpuddled direct seeded condition. Puddling practice was conducive for rice, unpuddled soil found to be optimum for succeeding deep rooted crops like vegetable cowpea.

Key words: Crop geometries, Establishment index, Grain yield, Root shoot ratio, Water productivity, Rice -Vegetable cowpea cropping system.

Rice is a survival food for half of the global population, as a key contributor of food security; lowland rice based cropping system belongs to most crucial system on earth. The average seasonal consumptive use of water for rice cultivation is 795 mm, where 53 per cent of this quantity is used for evaporation and 45 per cent for percolation. Asia is a home to 250 million marginal (< 1 ha) rice farms in which 39 per cent of rice produced from seeds instead of seedlings with least water foot print of 0.32-1.20 kg m^{-3} (Bouman and Tuong, 2003). Impervious layer (plough zone) created in puddled condition causes sub surface hardening leads to detrimental effect on succeeding deep rooted crops. After shifting from transplanting to direct seeding, crop stand establishment a critical factor determines resources productivity affecting subsequent growth, development and yield in rice. Rice grown under unpuddled unsaturated condition attains high productivity under -20 to -40 kPa of soil moisture tension that saves 20-35 per cent of water (IRRI, 2014). Plant geometry, is a crucial factor to exploit the potential of genotypes and to the extent exploitation of soil and solar radiation for higher productivity. Hence, it is necessary to determine the required plant density for higher resource use efficiency and productivity ha^{-1} under various crop establishment techniques. Among Rice based cropping systems, rice-legume cropping system is one of the most important cropping systems for soil nutrient balance and also well-fit into rice fallow system to retreat monsoon. Sequencing rice with vegetable cum legume such as vegetable cowpea will be a remunerative system. Hence, the present study was designed to add a suitable and profitable leguminous crops like vegetable cowpea in the rice based cropping systems with an objective to evaluate the effect of crop establishment techniques and crop geometries on productivity of rice and succeeding vegetable cowpea.

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Materials and Methods

A field experiment was carried out to evaluate the crop establishment techniques and various crop geometries on rice-vegetable cowpea cropping system during *rabi* (October-January) season of 2013-14 and during summer (February-May) season of 2014 in Department of Farm Management, Agricultural College and Research Institute, Madurai. Experimental site is located at southern agro climatic zone of Tamil Nadu at 9° 54’ N latitude and 78° 54’ E longitude with an elevation of 147 m above MSL.

The quantity of precipitation received through rainfall during period of sequential cropping i.e. October 2013- May 2014 was 240.6 mm and distributed in 18 rainy days. Experiment was laid out by strip plot design and the treatments were replicated thrice. The soil of the experimental field was clay loam in texture belonging to *Typic Ustropept*. The nutrient status was low in available nitrogen, medium in available phosphrous and high in available potassium. The treatment combinations includes four crop establishment techniques *viz.,* Puddled transplanting (E_1), Unpuddled transplanting (E_2), Puddled direct seeding (E_3) and Unpuddled direct seeding (E_4) and four crop geometries such as 30 cm x 20 cm (S_1), 20 cm x 10 cm (S_2), 25 cm x 25 cm (S_3) and 30 cm x 30 cm (S_4). Rice variety ADT 39 was chosen for the study. Rice seedlings with an age of 18 days were transplanted in puddled and unpuddled soil conditions with various crop geometries as per the treatment schedule (E_1 and E_2). For puddled and unpuddled direct seeded condition, seeds were treated with Azospirillum at 600 g kg^{-1} as pre sowing seed treatment and then 2-3 seeds were placed manually as per the spacing treatment (E_3 and E_4). For puddled transplanting, experimental plots were irrigated to 2 cm depth uniformly in all the treatments after the appearance of hair line cracks, upto panicle initiation stage. After panicle initiation, the plots were irrigated to 5 cm depth on disappearance of ponded water. Irrigation was stopped 15 days prior to harvest. In puddled direct seeding, before sowing, the field was drained to keep it under saturated condition to facilitate easy sowing and uniform establishment of seedlings. A thin film of water was maintained at the time of sowing. For the next 8-15 days, irrigation and drainage of water were alternated to facilitate aeration and adequate moisture for germination of seeds and establishments of seedlings. Thereafter, the plots were irrigated upto soil saturation, uniformly in all the treatments after the appearance of hair line cracks, upto panicle initiation stage. After panicle initiation, the plots were irrigated to 5 cm depth on disappearance of ponded water. Irrigation was stopped 15 days prior to harvest. For unpuddled transplanting, prior to transplanting, the soil was saturated and a thin film of water was stagnated during transplanting. For the next 8-15 days, irrigation and drainage of water were alternated to facilitate aeration and adequate moisture for establishments of seedlings. Subsequently irrigation scheduled to saturate the soil at critical stages of crop growth. In case of unpuddled transplanting, after sowing, life saving irrigation was done on 3 DAS to promote seed germination. Further, irrigation was given at critical stages of crop water requirement. Succeeding vegetable cowpea was raised without disturbing the layout of rice crop. Vegetable cowpea seeds were dibbled in between rice stubbles as per the spacing treatment, scheduled for rice. After life saving irrigation, plots were irrigated with ten days interval. Five plants in each plot were selected at random and labeled for recording observations in all the three replications. Observations on plant height, tillers m^{-2}, productive tillers m^{-2}, days to 50% panicle initiation, effective tiller (%), filled grains $panicle^{-1}$, grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) were recorded. For vegetable cowpea observations made on seed emergence, days to 50% flowering, vegetable yield (kg ha^{-1}) and halum yield (kg ha^{-1}) Based on morphological features and yield, root shoot ratio, water productivity (kg ha mm^{-1}), establishment index and harvest index were arrived for both the crops.

Root shoot ratio

Partitioning of biomass between root and shoot with an advancement of crop growth phases was calculated with the formula given by Pellerin (1993)

$$\text{Root shoot ratio} = \frac{\text{Root weight (g)}}{\text{Shoot weight (g)}}$$

Establishment index (EI)

Seedling establishment index was calculated following Association of Official Seed Analysis (1983) by using the formula

$$\text{EI} = \frac{\text{Number of emerged seedlings}}{\text{Days of first count}} + \frac{\text{Number of emerged seedlings}}{\text{Days of final count}}$$

The data on various biometrics recorded during the course of investigation were statistically analyzed as suggested by Gomez and Gomez (2010).

Water productivity

Water productivity was estimated as the ratio of yield obtained and the total water used to produce the yield and expressed in kg ha^{-1}/mm and the formula given by Sarkar *et al.* (2002).

$$\text{Water productivity (kg ha mm}^{-1}\text{)} = \frac{\text{Productivity obtained (kg ha}^{-1}\text{)}}{\text{Quantity of water used (mm)}}$$

Results and Discussion

Effect on growth parameters of rice

The growth attributes of rice are given in Table 1 and derived parameters such as water productivity, root shoot ratio and establishment index are given in Table 2.

Plant height and tillers m^{-2}

Plant height indicates the health and vigour of a crop. It is directly proportional to the development of root system and availability of nutrients to the plants. Taller plants were recorded in puddled transplanted rice (57.69 cm and 82.42 cm) at active tillering and panicle initiation stages, respectively. Whereas, shorter plants were observed in unpuddled condition transplanting (46.19 cm) and direct seeding (65.99 cm). Irrespective of the treatment combinations, puddled transplanting (E_1) found to be superior in growth attributes. The maximum plant height (59.82) was recorded in puddled transplanting combined with wider spacing of 30 cm x 30 cm. Wider spacing enabled exploitation of maximum solar radiation, nutrient and water extraction which might have led to higher plant height. Whereas, maximum number of tillers m^{-2} (392.8) and productive tillers m^{-2} (369.3) were registered in 25 cm x 25 cm spacing adopted under puddled transplanted condition. Formation of more number of phytomers produced profuse tillers in square planting under puddled condition as earlier reported by Oteng *et al.* (2013).

Table 1. Crop establishment techniques and crop geometries on growth attributes in rice-vegetable cowpea cropping system

CET/Spacing	Plant height at active tillering (cm)					Plant height at panicle initiation (cm)				
	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean
S_1- 30 x 20 cm	58.90	51.35	47.58	50.07	51.97	84.15	73.35	67.96	71.52	74.25
S_2 - 20 x 10 cm	54.50	46.97	43.46	45.91	47.71	77.86	67.10	62.09	65.58	68.16
S_3 - 25 x 25 cm	57.54	50.01	45.14	48.91	50.40	82.21	71.44	64.49	69.88	72.00
S_4 - 30 x 30 cm	59.82	52.36	48.60	51.14	52.98	85.45	74.80	69.42	73.06	75.68
Mean	57.69	50.17	46.19	49.01		82.42	71.67	65.99	70.01	
CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S x CET		
S. Ed	1.59	1.18	6.23	6.21		1.52	1.10	6.18	6.22	
CD (P = 0.05)	3.89	2.89	13.92	13.50		3.71	2.70	13.89	13.68	
CET/Spacing	Tillers m^{-2} at active tillering					Productive tillers m^{-2} at maturity				
	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean
S_1- 30 x 20 cm	392.8	379.5	274.4	387.0	358.4	369.3	349.1	214.0	352.2	321.2
S_2 - 20 x 10 cm	356.4	289.6	266.2	292.3	301.3	306.4	308.7	196.3	340.4	288.0
S_3 - 25 x 25 cm	416.4	407.7	307.4	414.5	386.5	389.4	379.2	242.8	381.3	348.2
S_4 - 30 x 30 cm	284.3	278.4	207.4	295.9	266.5	271.6	261.7	168.0	275.2	244.1
Mean	562.0	548.9	404.3	541.4		484.1	462.2	305.3	449.8	
	CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S x CET	
S. Ed	14.30	11.21	70.02	70.30		9.36	10.52	46.15	46.02	
CD (P = 0.05)	34.98	27.42	155.26	153.47		22.91	25.75	102.33	102.91	

E_1- PT- Puddled transplanting E_2- PDS- Puddled direct seeding E_3- UPT- Unpuddled transplanting E_4- UPDS- Unpuddled direct seeding

Establishment index

Stand establishment techniques alone had significant effect on establishment index of rice. Higher seed germination and seedling establishment (0.98) was noticed under unpuddled direct seeded condition while unpuddled transplanting showed higher seedling mortality and least stand establishment (0.84).

Table 2. Crop establishment techniques and crop geometries on establishment and water productivity in rice-vegetable cowpea cropping system

CET/Spacing	Establishment index					Root shoot ratio				
	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_4-UPDS	Mean
S_1- 30 x 20 cm	0.96	0.95	0.84	0.95	0.93	0.38	0.43	0.45	0.45	0.43
S_2 - 20 x 10 cm	0.97	0.97	0.85	0.99	0.94	0.44	0.42	0.43	0.46	0.44
S_3 - 25 x 25 cm	0.96	0.97	0.85	0.98	0.94	0.38	0.42	0.44	0.45	0.42
S_4 - 30 x 30 cm	0.96	0.96	0.84	0.98	0.93	0.33	0.40	0.43	0.43	0.40
Mean	0.96	0.96	0.84	0.98		0.38	0.42	0.44	0.45	
	CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S x CET	
S .Ed	0.01	0.01	0.04	0.04		0.01	0.01	0.05	0.05	
CD (P = 0.05)	0.05	NS	NS	NS		0.02	0.02	0.12	0.12	

CET/Spacing	Water productivity (kg ha mm^{-1})				
	E_1-PT	E_2-PDS	E_3-UPT	E_4 UPDS	Mean
S_1- 30 x 20 cm	1.66	2.60	3.18	4.19	2.91
S_2 - 20 x 10 cm	1.57	2.50	3.17	3.72	2.74
S_3 - 25 x 25 cm	1.73	1.97	3.32	4.49	2.88
S_4 - 30 x 30 cm	1.30	2.80	2.70	4.56	2.84
Mean	1.56	2.47	3.09	4.24	
	CET	Spacing	CET x S	S x CET	
S. Ed	0.08	0.05	0.29	0.30	
CD (P = 0.05)	0.19	0.12	0.66	0.65	

E_1- PT- Puddled transplanting E_2- PDS- Puddled direct seeding E_3- UPT- Unpuddled transplanting E_4- UPDS- Unpuddled direct seeding

Root shoot ratio

Establishment methods significantly influenced root proliferation and penetration. Unpuddled direct seeding produced high root: shoot dry weight (0.45) due to starvation for water and nutrients during seedling phase diverted energy to produce more seminal roots while in puddled zone was conducive for extraction of water and nutrients to transplanted rice (0.38).

Water productivity of rice

Water productivity was higher in unpuddled situation (transplanting : 3.09 kg ha mm^{-1}, direct seeding - 4.24 kg ha mm^{-1}) than in puddled condition (transplanting : 1.56 kg ha mm^{-1}, direct seeding - 2.47 kg ha mm^{-1}). The increased water input in puddled soil because of high percolation may outweigh the water savings during land preparation in unpuddled condition that led to higher water productivity (Bouman *et al.,* 2002).

Table 3. Crop establishment techniques and crop geometries on yield attributes and yield in rice-vegetable cowpea cropping system

CET/Spacing	Days to 50% panicle initiation					Effective tiller (%)					Filled grains panicle^{-1}				
	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean
S_1- 30 x 20 cm	76.93	66.20	62.47	65.33	67.73	94.50	93.00	79.50	92.10	89.38	268.3	262.0	220.1	250.0	250.0
S_2 - 20 x 10 cm	75.10	65.87	62.47	64.67	67.14	79.50	76.25	72.30	74.40	75.13	230.4	220.2	204.4	210.0	216.0
S_3 - 25 x 25 cm	76.00	66.27	62.93	65.30	67.56	96.60	94.05	81.01	93.20	90.90	275.1	264.0	235.0	258.0	258.1
S_4 - 30 x 30 cm	76.00	66.13	62.50	64.30	67.23	94.00	92.10	78.20	91.10	88.75	262.2	255.1	224.3	236.0	244.3
Mean	76.01	66.12	62.64	64.90		90.40	88.75	77.50	87.50		259.3	250.1	221.2	239.0	
	CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S xCET		CET	Spacing	CET xS	S x CET	
S. Ed	1.50	2.53	8.20	8.07		1.19	1.50	1.80	1.70		6.40	4.50	31.6	31.8	
CD (P=0.05)	3.66	6.20	18.06	18.48		2.90	3.66	4.45	4.19		15.66	11.02	70.03	68.92	

CET/Spacing	Grain yield (kg ha^{-1})					Straw yield (kg ha^{-1})				
	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean
S_1- 30 x 20 cm	6686	5141	3693	5633	5288	9012	8008	4714	7194	7232
S_2 - 20 x 10 cm	6317	4565	3679	5425	4997	8698	7838	4734	6562	6958
S_3 - 25 x 25 cm	6963	5516	3850	4264	5148	9299	8478	4864	7596	7559
S_4 - 30 x 30 cm	5246	5600	3129	6068	5010	7375	6403	4012	7725	6379
Mean	6303	5205	3588	5347		8596	7682	4581	7269	
	CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S x CET	
S. Ed	113	84	513	515		181	163	1090	1091	
CD (P = 0.05)	277	205	1143	1127		442	400	2384	2373	

E_1- PT- Puddled transplanting E_2- PDS- Puddled direct seeding E_3- UPT- Unpuddled transplanting E_4- UPDS- Unpuddled direct seeding

Effect on yield and yield attributes

The data on rice yield and yield parameters are presented in Table 3.

Days to 50% panicle initiation

Days to 50% panicle initiation was higher (76 days) in the combination of puddled transplanting and square planting of 25 cm x 25 cm spacing. Lesser duration of 62.64 days registered in unpuddled transplanting with 20 cm x 10 cm spacing. Under unpuddled condition poor crop establishment, lesser proliferation of seminal roots led to sub optimal utilization of water and nutrient might have shortened the vegetative phase of rice and consequently panicle emergence occured earlier. Similarly in 20 cm x 10 cm spacing, higher density per unit area increased competition between plants, resulting in earlier emergence of panicle. However, it was comparable with wider crop geometries.

Productive tiller (%)

Effective tiller per centage was higher in square planting of 30 cm x 30 cm (90.9%) and 25 cm x 25 cm (88.75%). It was comparable with 30 cm x 20 cm (89.38%). Among various planting methods, in puddled transplanting, ratio between total number of tillers to number of productive tillers found to be higher and it was comparable with direct seeding in puddled and unpuddled conditions. Among the various planting geometries closer spacing of 20 cm x 10 cm converted least percentage (75.13%) of productive tillers. Interaction effect showed that higher (96.60%) was registered in the combination of puddled transplanting with 30 cm x 30 cm spacing.

Filled grains panicle^{-1}

Wider crop geometry of 30 cm x 30 cm under puddled transplanting (275.1) was found to be superior while unpuddled transplanting with 20 cm x 10 cm spacing produced lower (204.4) filled grains per panicle. It indicated that chaffy grain was higher under unpuddled transplanted condition and closer spacing of 20 cm x 10 cm due to shorter period of vegetative phase, assimilate accumulation might be low, subsequently translocation and grain filling was lower. In case of seedlings placed in square planting under puddled condition offered optimal utilization of resources ensured higher assimilate accumulation and partitioning that led to higher fertility of rice grain.

Grain and straw yield

Square planting of 25 cm x 25 cm produced 5148 kg ha^{-1}, however it was comparable with 30 cm x 30 cm (5010 kg ha^{-1}) and 30 cm x 20 cm (5288 kg ha^{-1}). Lower grain yield of 4997 kg ha^{-1} obtained in rice planted in the spacing of 20 cm x 10 cm. Similar trend was noticed in straw yield also. Results indicated that wider spacing had linearly increasing effect on the performance of individual plants. The plants grown with wider spacing have more area of land around them to draw the nutrition and had more solar radiation to absorb for better photosynthetic process and hence performed better as individual plants. The reason for deviation of this linearity in case of grain yield per plot is that the yield does not entirely depend upon the performance of individual plant but also on the total number of plants per plot and yield contributing parameters within plant. Higher grain yield of 6963 kg ha^{-1} and straw yield of 9299 kg ha^{-1} were obtained under the combination of puddled transplanting with 25 cm x 25 cm spacing (Oteng *et al.,* 2013).

Among various crop establishment techniques, puddled transplanted crop produced higher yield of 6303 kg ha^{-1}, unpuddled transplanting attained lower productivity of 3588 kg ha^{-1}. In case of direct seeding in unpuddled condition resulted in a grain yield of 5347 kg ha^{-1} which was comparable with puddled direct seeding (5205 kg ha^{-1}). The straw yield was in same trend. This might be due to conducive soil rhizoshere created in puddled condition provided faster recovery from transplanting shock and enabled extraction of nutrients and water from root zone. In case of unpuddled transplanted condition, prolonged transplanting shock and seedling mortality led to poor establishment. Energy diverted to overcome initial stress putforth lesser biomass prodution and grain yield. Under unpuddled direct seeded condition, with an alternate drying and wetting, initially biomass production diverted to roots rather than shoots also energy spent to convert N-NO_3 to N-NH_4. This is in accordance with the finding of Bouman et al. (2005) who had reported energy required to convert N-NO_3 to N-NH_4 was higher than direct uptake of N-NH_4 and subsequently it would reduce shoot biomass accumulation.

Thus it could be concluded that puddling is optimum for rice growth. However, unpuddled direct seeding will be an alternate establishment method where rice raised as monsoon dependent crop. Square planting with a 25 cm x 25 cm found to be optimum for obtaining higher yield in rice.

Vegetable cowpea

The data on growth and yield attributes of vegetable cowpea are given Table 4.

Table 4. Crop establishment techniques and crop geometries on growth and yield of vegetable cowpea

CET/Spacing	Emergence index					Water productivity (kg ha mm^{-1})					Days to 50% flowering				
	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean
S_1- 30 x 20 cm	0.89	0.90	0.94	0.97	0.92	8.13	8.01	9.87	11.61	9.41	39.50	41.50	44.50	45.50	42.75
S_2 - 20 x 10 cm	0.89	0.90	0.97	0.97	0.93	6.77	6.67	8.23	9.68	7.84	37.52	38.50	42.30	41.25	39.89
S_3 - 25 x 25 cm	0.90	0.91	0.97	0.96	0.94	8.49	8.36	10.31	12.13	9.82	40.00	43.50	45.00	44.75	43.31
S_4 - 30 x 30 cm	0.90	0.90	0.96	0.97	0.93	9.91	9.76	12.04	14.16	11.47	40.00	44.50	45.00	45.70	43.80
Mean	0.89	0.90	0.96	0.97		8.33	8.20	10.11	11.89		39.26	42.00	44.20	44.30	
	CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S xCET		CET	Spacing	CET x S	S x CET	
S. Ed	0.02	0.02	0.11	0.11		0.18	0.26	0.75	0.74		0.93	0.95	6.16	6.16	
CD (P=0.05)	0.05	0.05	0.22	0.22		0.45	0.63	1.70	1.72		2.29	2.34	13.41	13.42	
CET/Spacing	Vegetable yield (kg ha^{-1})					Halum yield (Fresh weight) (kg ha^{-1})					Harvest index				
	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean	E_1-PT	E_2-PDS	E_3-UPT	E_1-UPDS	Mean
S_1- 30 x 20 cm	5040	4964	6120	7200	5831	9509	10334	10737	13585	11041	0.46	0.44	0.50	0.46	0.47
S_2 - 20 x 10 cm	4200	4137	5100	6000	4859	8571	8619	10000	12578	9942	0.43	0.42	0.44	0.43	0.45
S_3 - 25 x 25 cm	5264	5185	6392	7520	6090	9571	9783	11113	13926	11098	0.48	0.46	0.50	0.47	0.49
S_4 - 30 x 30 cm	6146	6054	7463	8780	7111	10782	11007	12589	13303	11920	0.50	0.48	0.52	0.57	0.48
Mean	5163	5085	6269	7375		9609	9936	11110	13348		0.46	0.43	0.48	0.51	
CET	Spacing	CET x S	S x CET		CET	Spacing	CET x S	S xCET		CET	Spacing	CET xS	S x CET		
S. Ed	121	105	685	686		254	243	1709	1710		0.01	0.01	0.05	0.05	
CD (P=0.05)	296	258	1504	1495		623	595	3716	3709		0.02	0.02	0.12	0.12	

E_1- PT- Puddled transplanting E_2- PDS- Puddled direct seeding E_3- UPT- Unpuddled transplanting E_4- UPDS- Unpuddled direct seeding

Emergence index

Vegetable cowpea well established under unpuddled condition (direct seeding- 0.97 and transplanting – 0.96). In upland condition, dispersal of soil particles and capillarity favored better establishment of rhizosphere for moisture and nutrient uptake. In puddled soil, 25 cm of surface puddled zone created hard pan restricted root penetration led to poor establishment (0.89).

Water productivity

In unpuddled direct seeded soil, due to high particle density, optimum proportion of macro and micro pores offered rapid infiltration, thus increased water holding capacity of soil. Also proper establishment of root zone in wider spacing of 30 cm x 30 cm contributed for higher water productivity (14.16 kg^{-1} ha^{-1} mm^{-1}). Least water productivity of 6.77 kg^{-1} ha^{-1} mm^{-1} recorded in the combination of 20 cm x 10 cm puddled transplanting, since maximum quantity of irrigated water evaporated immediately after irrigation due to stagnation of water on surface hard pan. Puddling destroyed pore space in soil, owing to least water infiltration and retention in soil.

Days to 50% flowering

Period of vegetative phase was long (45.7 days) under the combination of unpuddled direct seeding with 30 cm x 30 cm spacing while shortened period of 37.52 days was registered in puddled transplanting with 20 cm x 10 cm due to sub optimal utilization of nutrient and moisture.

Vegetable yield and Halum yield (fresh weight)

Establishment techniques adopted for rice and crop geometries had significant influence on green pod and halum yield. Higher yield of 8780 kg ha^{-1} was harvested under unpuddled transplanting with 30 cm x 30 cm, favourable micro-climatic conditions, availability of uniform and adequate moisture for plant growth and keeping the soil structure loose and friable,which was conducive to good aeration resulting in the better growth and partitioning of DMP. In case of higher halum yield of 13926 kg ha^{-1} recorded under square planting of 25 cm x 25 cm in unpuddled direct seeded condition, due to high plant density than 30 cm x 30 cm spacing (13303 kg ha^{-1}).

Harvest index

High biomass partioning (0.57) obtained in unpuddled direct seeding with 30 cm x 30 cm. The haulm yield in same treatment though not significant, which indicated the better vegetative growth of the crop without any concomitant increase in pod yield.

From the above data it can be concluded that, puddled transplanting with square planting of 25 cm x 25 cm is optimum for rice, while vegetable cowpea yield was higher under unpuddled direct seeded condition with wider spacing of 30 cm x 30 cm spacing. Unpuddled direct seeding will be economically viable and water wise technique for monsoon dependant rice-vegetable cowpea cropping system.

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