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Research Paper

Input optimization in short duration red gram [*Cajanus cajan* (L.) Millsp.] for the agri-food systems in southern Kerala

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ABSTRACT

In the present study, a field experiment was laid out to assess the suitability of two short-duration varieties of red gram and standardize the agronomic management practices. The treatments included combinations of two varieties, two spacings, and three nutrient levels. Individual effects of the variety, APK 1, narrow spacing, and the highest nutrient level were found superior for yield and its contributing attributes. The pooled analysis registered the highest seed yield (1.38 t ha^{-1}) in the combination APK 1 + 40 cm × 20 cm + 40:80:40 kg NPK ha^{-1}. The net returns and benefit-cost ratio were also the highest. Soil available nutrient status was found to be augmented with the cultivation, with wider spacing and the highest nutrient dose recording maximum post-harvest soil NPK contents. The results proved that the variety APK 1 and the agronomic management of 40 cm × 20 cm spacing with 40:80:40 kg NPK ha^{-1} are most suitable for red gram cultivation in southern Kerala.

Key words: Economics, Nutrient levels, Short duration, Red gram, Spacing, Soil, Variety

INTRODUCTION

The COVID -19 pandemic has brought to focus the impending need for a balanced and healthy diet among the population for resilience and immunity build up. Prevalence of malnutrition in hospitalized COVID patients was reported to the tune of 42 to 67% (Bedock *et al*. 2020) hinting it to be a driving factor for the fatal disease. Nutritional deficiencies of energy, protein, and specific micronutrients are associated with depressed immune function and increased susceptibility to infection during disease outbreaks (Naja and Hamadeh 2020). Strengthening the immune system through optimal nutrition and dietary nutrient intake is echoed as a plausible and sustainable way to survive pandemic events.

With its miraculous nutritional profiles, pulses also called grain legumes, offer a potent solution to protein-calorie-mineral malnutrition, in combination with cereals. Further, these are rich sources of vitamins and minerals with low glycemic index, and gluten content and act as functional foods (Rao 2002), fostering multiple health benefits to the consumers. Pulses are often referred to as "poor man's meat" since they provide a low-cost source of protein to a broader population. However, per capita consumption of pulses has always been below the recommended levels. The World Health Organization (WHO) recommends 80 g of pulses man^{-1} day^{-1}. The Indian Council of Medical Research (ICMR) suggests 40 g of pulses man^{-1} day^{-1}. The actual availability, however, varies between 30 and 35 g pulses man^{-1} day^{-1}. As a result, pulse farming must be bolstered as a means of combating malnutrition.

According to Gull *et al*. (2020), pulses are climate-smart, can be imbibed in any cropping system, and can also act as catch crops because they have a deep rooting system, phenotypic plasticity, dehydration tolerance, high moisture retention capacity, and a wide range of photothermal sensitivity.

Red gram [*Cajanus cajan* (L.) Millsp.] also known as pigeon pea, arhar and tur, is the major *Kharif* pulse crop in India cultivated in an area of 4.78 million ha with a productivity averaging 751 kg ha^{-1} (DACFW 2019). The grain legume is a rich source of protein, carbohydrates, minerals, and vitamins. It contains 20 - 22 % protein, 51.4 - 58.8 % carbohydrate, 1.2 - 8.1 % crude fibre, and 0.6 - 3.8 % lipid (Faris and Singh 1990). The seeds can be consumed either as decorticated splits or in the form of green seeds as vegetable. The considerable tolerance to drought, high N fixing ability, and C sequestration potential make red gram a potential crop for inclusion in climate mitigation strategies.

The varieties cultivated in the country are mostly of medium duration (150 - 200 days). Recent breeding advances have led to the development of short and extra short-duration varieties (120 - 150 and 90 -120 days, respectively) which fit well in the cropping systems favoring higher cropping intensities and diversities.

Red gram, although widely cultivated in India, in the southernmost state, Kerala, cultivation is confined to Palakkad district, the area being a meagre, 181 ha, and production of 299 tonnes (FIB 2024). Nevertheless, the pulse is a regular component/ingredient in the daily cuisines of the natives, and promotion of its cultivation, especially short-duration varieties, in agri-food systems of the state, would complement the total pulse production, sustain soil fertility and make it an efficient component in the existing cropping systems.

Research specific to the varietal suitability and management practices for red gram in Kerala is practically nil. Hence taking into account the significance of the crop as a pulse and food crop, a field experiment was attempted to identify a short-duration variety suitable for Kerala and to standardize its agronomic management for recommendation and adoption.

MATERIALS AND METHODS

The experiment was conducted in the Instructional Farm of the College of Agriculture, Vellayani, Thiruvananthapuram Kerala, located at 8.5° N latitude, 76.9° E longitude, and at an altitude of 29 m above mean sea level (MSL). It was laid out in factorial RBD during the *Rabi* season (November to March) in 2018 - 2019 and repeated for confirmation in 2019 – 2020. The soil belonged to the sandy clay loam textural class and was acidic in pH, low in available N, medium in K, and high in available P. The treatments included two short-duration red gram varieties *(v):* APK 1, Vamban (Rg) 3, two spacings (s): 40 cm x 20 cm, 60 cm x 30 cm, and three NPK doses (n): 40:80:40, 30:60:30 and 20:40:20 kg NPK ha^{-1}. The varieties were released from Tamil Nadu Agricultural University (TNAU). APK 1 is a pure line selection from ICPL 87101, which matures in 95-105 days, while Vamban (Rg) 3 developed through pedigree selection from a cross Vamban 1 × Gulbarga that matures in 100-105 days.

The experimental area was cleared, ploughed thoroughly, leveled, and converted into plots as per the layout of the experiment. Lime was applied @ 850 kg ha^{-1} during the first year and @ 250 kg ha^{-1} in the second year based on soil test results and package of practices recommendations (KAU 2016). Seeds were treated with *Rhizobium* (@ 50 g kg seed^{-1}) dried under shade for 30 minutes and then sown, adopting a seed rate of 15 kg ha^{-1} at the spacings envisaged in the treatments after farmyard manure application (12.5 t ha^{-1}) and incorporation. Fertilizers (urea, rajhos and muriate of potash) were applied as per the treatments and based on the soil test results and NPK ratings and recommendations (KAU 2016). The entire dose of P was applied as basal, N and K, in two splits, as basal and at 30 DAS. Thinning and gap filling were done at 15 days after sowing (DAS) and weedings at 15 and 30 DAS. Irrigation was given whenever rains failed. The crop was harvested manually by picking the pods when the leaves and pods turned reddish-brown and shedding became prominent. Border plants and the net plot area were harvested separately and pods were shade-dried, threshed, and winnowed to separate the seeds. The weight of seeds from individual plots was recorded and expressed in kg ha^{-1}.

The soil pH and available NPK status were analyzed after the experiment and the economics of cultivation were computed based on the cost of cultivation and returns realized. The data were statistically analyzed using the analysis of variance technique (ANOVA) suggested by Panse and Sukhatme (1985) as applied to factorial RBD. Critical differences (CD) were calculated wherever treatments were found to be significant. Pooled analysis was done for seed yield, net return, and B:C ratio based on the data of the two years.

RESULTS AND DISCUSSION

Growth attributes

Plant height

The effect of varieties, spacing, and nutrient levels on plant height at monthly intervals during the two years are presented in Tables 1a and b. During the first year of study, plant height at 30 DAS did not vary significantly with either the variety, the spacing, or the nutrient level. At 60 DAS and harvest, the variety Vamban (Rg) 3 (v_2) recorded the significantly tallest plants (106.55 and 121.26 cm, respectively). Among the interactions, maximum plant heights were recorded in $v_2s_2n_3$ (Vamban (Rg)

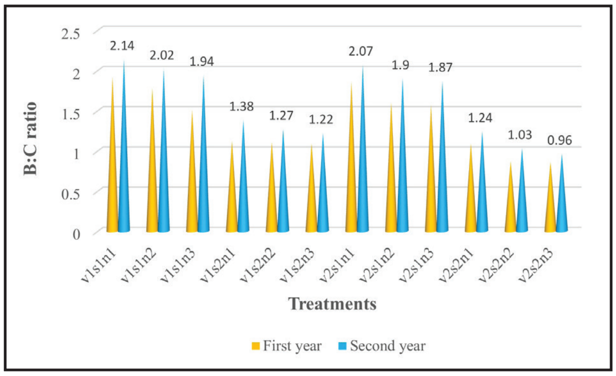

Fig. 1. Effect of V × S × N interaction on B:C ratio during the first and second year

3 at 60 cm × 30 cm and 20:40:20 kg NPK ha^{-1}) at 60 DAS and harvest respectively, on par with $v_2s_2n_1$.

In the second year, varieties and nutrient levels exerted significant influence on plant height with Vamban (Rg) 3 and 40:80:40 kg NPK ha^{-1} recording maximum plant heights at 30, 60 DAS, and harvest. The wider spacing (60 cm × 30 cm) resulted in the tallest plants at 60 DAS and harvest. Among the interactions, as in the first year, plants were taller in Vamban (Rg) 3 planted at wider spacing and fertilized at 20:40:20 kg NPK ha^{-1}.

Number of branches per plant

The data presented in Tables 1a and b show that the individual effects remained non -significant during the first year at 30 DAS. However, at 60 DAS and harvest, variety Vamban (Rg) 3 (v_2), spacing 60 cm × 30 cm (s_2) and nutrient level 20:40:20 kg NPK ha^{-1} (n_3) recorded the significantly highest number of branches per plant, and the effects were manifested in the two-factor interactions also. The interaction, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm × 30 cm + 40:80:40 kg NPK ha^{-1}) recorded the highest number of branches per plant at 60 DAS and harvest, which was on par with $v_2s_2n_3$ at both stages (Table 1b).

The trend remained similar during the second year, Vamban (Rg) 3 and 40:80:40 kg NPK ha^{-1} were superior at 30, 60 DAS, and harvest. The effect of spacing was significant only at harvest and the wider spacing, resulted in the maximum number of branches (8.9). As in the first year, $v_2s_2n_1$ registered the significantly highest number of branches per plant at 60 DAS and harvest (Table 1b).

The growth characters in red gram were significantly influenced by the treatments *viz*., varieties, spacing, and nutrient levels. APK 1 was found to be shorter in stature and of a less branching nature compared to Vamban (Rg) 3 following the characters assigned to the varieties by their parental institutes. The differences in plant characteristics of the two varieties are attributed to the genetic makeup (Poehlman 1991).

Plant height and number of branches were significantly greater under wider spacing. It is reasoned that the wider spacing assured an adequate supply and optimum utilization of growth resources in individual plants due to the lower plant density, 5 plants m^{-2} in 60 cm × 30 cm compared to 12 plants m^{-2} in 40 cm × 20 cm spacing. Earlier reports document enhanced plant heights with shading under closer spacing (Mane *et al*. 2008, Diwan *et al*. 2018). However, contrary to this in the present study, the plants were taller under wider spacing in both years. Red gram plants have an architecture with branches of almost erect orientation and hence it is assumed that the shading and elongation that would have otherwise occurred when closely planted did not happen The results obtained corroborate the findings of Dhandayuthapani *et al.* (2015). The higher number of branches observed under wider spacing is in line with the reports of Mula *et al.* (2010). Anuradha *et al.* (2020) have recommended high-density planting in early maturing types of red gram.

The significance of nutrient management in red gram is well documented (Tiwari *et al.* 2011). Each nutrient has its specific role in the expression of growth characteristics and balanced application assumes prime importance (Nath *et al.* 2009, Patil *et al.* 2012, Singh *et al.* 2015). Growth attributes were superior with the application of nutrients, @ 40:80:40 kg ha^{-1}. It is inferred that the application of N, P, and K at higher levels enhanced tissue differentiation and expansion resulting in taller plants and production of a higher number of branches per plant. The results conform with the findings of Shivran *et al*. (2000) and Kantwa *et al.* (2005).

Number of nodules per plant

The variations in the number of nodules per plant recorded at flowering (Table 1a) due to individual and interaction effects were non-significant during the first year. However, in the second year, spacing exerted significant influence and it was the highest (6.2) at closer spacing, 40 cm × 20 cm (s_1). The V × S × N interaction effects were non-significant.

Table 1a. Effect of varieties, spacing and nutrient levels on growth attributes in red gram

Treatments	Plant height (cm)						No. of branches/plant						No. of nodules/ plant		Weight of nodules/plant (g)	
	I year			II year			I year			II year			I year	II year	I year	II year
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest				
Varieties (V)																
v_1: APK 1	50.06	93.99	96.09	49.13	93.53	105.04	2.9	5.4	6.8	2.8	4.9	6.9	2.6	5.7	0.15	0.59
v_2: Vamban (Rg) 3	47.80	106.55	121.26	52.41	98.63	117.00	3.3	7.1	9.1	3.3	6.7	10.0	2.3	5.3	0.18	0.57
SEm±	1.34	2.02	2.39	0.05	0.60	0.60	0.30	0.27	0.28	0.07	0.27	0.16	0.44	0.29	0.04	0.01
CD (p=0.05)	-	5.912	7.021	0.142	1.751	1.751	-	0.793	0.818	0.199	0.788	0.462	-	-	-	-
Spacing (S)																
s_1: 40 cm x 20 cm	49.66	99.03	105.97	50.82	94.43	108.51	3.0	5.7	7.0	3.1	5.7	8.1	2.9	6.2	0.19	0.64
s_2: 60 cm x 30 cm	48.20	101.51	111.39	50.72	97.73	113.53	3.3	6.9	8.8	3.0	5.8	8.9	1.9	4.8	0.14	0.53
SEm±	1.34	2.02	2.39	0.05	0.60	0.60	0.30	0.27	0.28	0.07	0.27	0.16	0.44	0.29	0.04	0.01
CD (p=0.05)	-	-	-	-	1.751	1.751	-	0.793	0.818	-	-	0.462	-	0.842	-	0.022
Nutrient levels (N) kg NPK ha^{-1}																
n_1: 40:80:40	48.43	97.57	105.02	54.96	100.28	114.43	2.9	6.3	7.8	3.3	6.3	8.9	2.3	5.6	0.08	0.61
n_2: 30:60:30	49.26	100.24	107.85	51.01	97.70	112.35	3.1	5.6	7.2	3.2	5.3	7.8	2.5	5.6	0.16	0.59
n_3: 20:40:20	49.10	103.01	113.17	46.34	90.26	106.28	3.3	6.9	8.8	2.7	5.6	8.7	2.5	5.3	0.25	0.56
SEm±	1.64	2.47	2.93	0.06	0.73	0.73	0.37	0.33	0.34	0.08	0.33	0.19	0.54	0.35	0.05	0.01
CD (p=0.05)	-	-	-	0.174	2.144	2.144	-	0.972	1.002	0.243	0.965	0.566	-	-	-	0.027

Table 1b. Interaction effect of varieties, spacing, and nutrient levels on growth attributes in red gram

Treatments	Plant height (cm)						No. of branches/plant						No. of nodules/plant		Weight of nodules/plant (g)	
	I year			II year			I year			II year			I year	II year	I year	II year
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest				
$v_1s_1n_1$	51.41	91.07	93.13	51.33	95.95	106.38	3.1	4.5	5.9	2.6	4.9	6.4	3.0	5.7	0.07	0.57
$v_1s_1n_2$	51.43	94.42	94.02	48.50	88.10	98.75	3.0	4.8	5.9	3.3	4.5	6.1	2.7	5.3	0.07	0.54
$v_1s_1n_3$	52.70	99.55	102.33	43.33	83.75	96.16	3.5	5.9	7.0	3.0	5.2	7.1	3.3	6.3	0.33	0.65
$v_1s_2n_1$	50.47	94.47	96.77	55.24	104.85	116.43	3.4	6.9	7.8	3.7	5.8	8.3	3.0	7.3	0.17	0.77
$v_1s_2n_2$	48.50	96.20	96.40	50.13	104.70	116.68	2.3	4.5	6.1	2.3	4.4	6.5	2.0	5.7	0.07	0.59
$v_1s_2n_3$	45.83	88.27	93.92	46.23	83.80	95.82	2.5	6.1	7.9	2.1	4.3	7.3	1.3	3.7	0.20	0.44
$v_2s_1n_1$	45.53	97.80	104.24	59.16	100.15	114.83	1.8	4.6	5.9	2.8	6.4	9.6	1.7	5.3	0.03	0.58
$v_2s_1n_2$	48.30	104.43	118.57	53.20	102.10	119.67	3.4	6.9	8.5	3.9	6.2	9.4	4.0	7.3	0.43	0.79
$v_2s_1n_3$	48.57	106.93	123.51	49.40	96.55	115.29	3.2	7.4	9.1	2.9	7.0	9.9	2.7	7.0	0.20	0.68
$v_2s_2n_1$	46.29	106.93	125.93	54.09	100.15	120.06	3.7	9.3	11.7	4.3	8.2	11.6	1.3	4.0	0.07	0.50
$v_2s_2n_2$	48.81	105.90	122.40	52.20	95.90	114.30	3.7	6.3	8.2	3.2	6.3	9.2	1.3	4.0	0.07	0.42
$v_2s_2n_3$	49.30	117.30	132.93	46.40	96.95	117.86	4.1	8.2	11.3	2.8	6.0	10.3	2.7	4.0	0.27	0.45
SEm±	3.29	4.94	5.86	0.12	1.46	1.46	0.74	0.66	0.68	0.17	0.66	0.39	1.07	0.70	0.11	0.02
CD (p=0.05)	-	14.483	17.197	0.348	4.288	4.288	3.1	4.5	5.9	2.6	4.9	6.4	-	-	-	0.054

Weight of nodules per plant

A perusal of the data in Tables 1 a and b revealed that the treatments failed to evoke significant differences in the weight of nodules per plant whereas in the second year, s_1 and n_1 were found superior (0.64 and 0.61 g, respectively). Among the interactions, a markedly higher weight was observed in $v_2s_1n_2$.

The number of nodules per plant was comparatively lower in the first year, 1.3 to 4.0, whereas it ranged from 3.7 to 7.3 per plant in the second year. The *Rhizobium* that was used for inoculation in the first year was collected from TNAU, Coimbatore. It is speculated that the species did not establish well in the soil at the experimental site in Kerala due to the inherent soil properties, especially the acidic soil pH. However, in the second year, *Rhizobium* isolated from roots of red gram plants raised in the Crop Museum at Vellayani was cultured and used for the inoculation which resulted in more nodules on plant roots. This also brings to light the significance of specific strains and soil properties in the multiplication of bacteria and infection on red gram roots.

Nodulation was more prominent in the closely spaced plants. It is presumed that when closely planted, the root density was higher and hence the rhizospheric effects including the microbial activities were more dominant, facilitating root infection and nodulation. Better growth attributes

Table 2a. Effect of varieties, spacing, and nutrient levels on yield attributes and seed yield

Treatments	Days to 50 % flowering		Average pod weight (g pod^{-1})		Number of seeds per pod		100 seed weight (g)		Seed-pod ratio		Seed yield (kg ha^{-1})		
	I year	II year	I year	II year	I year	II year	I year	II year	I year	II year	I year	II year	Pooled
Varieties (V)													
v_1: APK 1	58.22	61.67	0.40	0.48	4.5	4.6	9.04	9.15	0.74	0.73	0.99	1.07	1.04
v_2: Vamban (Rg)3	69.33	70.06	0.34	0.46	4.4	4.6	8.08	8.73	0.76	0.74	0.92	0.97	0.94
SEm±	0.25	0.25	0.01	0.01	0.07	0.07	0.17	0.08	0.01	0.004	0.03	0.01	0.01
CD (p=0.05)	0.726	0.741	0.021	0.022	-	-	0.486	0.242	-	-	0.069	0.014	0.036
Spacing (S)													
s_1: 40 cm x 20 cm	63.61	66.11	0.38	0.51	4.4	4.6	8.46	8.92	0.76	0.73	1.19	1.28	1.24
s_2: 60 cm x 30 cm	63.94	65.61	0.37	0.43	4.5	4.5	8.66	8.96	0.74	0.74	0.72	0.76	0.74
SEm±	0.25	0.25	0.01	0.01	0.07	0.07	0.17	0.08	0.01	0.004	0.03	0.01	0.01
CD (p=0.05)	-	-	-	0.022	-	-	-	-	-	-	0.069	0.014	0.036
Nutrient levels (N) kg NPK ha^{-1}													
n_1: 40:80:40	64.25	65.83	0.38	0.50	4.5	4.7	8.68	9.10	0.76	0.78	1.06	1.11	1.08
n_2: 30:60:30	63.42	66.17	0.37	0.45	4.5	4.5	8.37	8.83	0.78	0.70	0.94	1.00	0.97
n_3: 20:40:20	63.67	65.58	0.37	0.44	4.4	4.6	8.63	8.88	0.72	0.74	0.88	0.96	0.91
SEm±	0.30	0.31	0.01	0.01	0.08	0.08	0.20	0.10	0.01	0.005	0.03	0.01	0.02
CD (p=0.05)	-	-	-	0.028	-	-	-	-	0.038	0.015	0.090	0.017	0.045

Table 2b. Effect of V × S × N interaction on yield attributes and seed yield in red gram

Treatments	Days to 50 % flowering		Pod weight (g pod^{-1})		Number of seeds per pod		100 seed weight (g)		Seed - pod ratio		Seed yield (kg ha^{-1})		Pooled mean
	I year	II year	I year	II year	I year	II year	I year	II year	I year	II year	I year	II year	
$v_1s_1n_1$	58.00	61.00	0.43	0.54	4.5	4.7	8.85	9.07	0.74	0.78	1.36	1.39	1.38
$v_1s_1n_2$	58.33	62.33	0.37	0.51	4.6	4.7	8.42	8.97	0.77	0.70	1.25	1.30	1.28
$v_1s_1n_3$	58.33	61.67	0.42	0.52	4.3	4.6	9.32	8.98	0.75	0.73	1.05	1.24	1.14
$v_1s_2n_1$	58.33	61.33	0.41	0.47	4.5	4.6	9.63	9.50	0.75	0.77	0.79	0.90	0.84
$v_1s_2n_2$	58.33	62.33	0.39	0.43	4.7	4.4	8.82	9.20	0.74	0.69	0.78	0.82	0.80
$v_1s_2n_3$	58.00	61.33	0.39	0.42	4.4	4.5	9.21	9.17	0.68	0.74	0.76	0.78	0.77
$v_2s_1n_1$	70.33	71.33	0.33	0.57	4.6	4.7	7.90	8.90	0.79	0.77	1.31	1.34	1.33
$v_2s_1n_2$	68.67	70.67	0.35	0.47	4.2	4.5	8.14	8.80	0.79	0.64	1.12	1.22	1.17
$v_2s_1n_3$	68.00	69.67	0.36	0.45	4.4	4.7	8.15	8.80	0.71	0.78	1.09	1.19	1.14
$v_2s_2n_1$	70.33	69.67	0.34	0.43	4.4	4.6	8.36	8.93	0.76	0.78	0.77	0.80	0.79
$v_2s_2n_2$	68.33	69.33	0.36	0.41	4.4	4.5	8.11	8.37	0.79	0.79	0.61	0.66	0.63
$v_2s_2n_3$	70.33	69.67	0.32	0.39	4.5	4.5	7.83	8.60	0.75	0.70	0.60	0.61	0.61
SEm ±	0.61	0.62	0.02	0.02	0.16	0.16	0.41	0.20	0.03	0.01	0.06	0.01	0.03
CD (p=0.05)	-	-	0.052	0.055	-	-	1.191	-	-	0.030	0.180	0.035	0.089

were recorded with the highest nutrient dose in this study. The short-duration red gram varieties responded to the balanced application of the major nutrients, and the increased shoot and root growth of plants would have also contributed to the larger-sized nodules through better photosynthesis and assimilate partitioning.

Yield attributes

Tables 2a and b depict the variations in yield attributes of red gram with the treatments.

Days to 50% flowering

Significant differences were observed in the number of days taken for 50 % flowering in both years. It was earlier in APK 1 (58.22 and 61.67 days during the first and second years, respectively) compared to the variety Vamban (Rg) 3 (69.33 and 70.06 days, respectively). However, the individual effects were not carried over to the combinations, and hence interaction effects remained non-significant.

Average pod weight

A perusal of the data on the average pod weight (Table 2a) revealed APK 1 to be superior (0.40 g pod^{-1}), but the effects of spacing and nutrient levels were not significant in the first year. The combination

Table 3a. Effect of varieties, spacing, and nutrient levels on soil pH and available NPK after harvest (kg ha^{-1})

Treatments	First-year				Second year			
	Soil pH	Available N	Available P	Available K	Soil pH	Available N	Available P	Available K
Varieties (V)								
v1: APK 1	4.82	176.91	72.27	253.96	5.71	228.97	129.97	270.60
v2: Vamban (Rg) 3	4.83	174.82	78.12	257.48	5.69	223.17	139.44	275.36
SEm±	0.04	0.07	0.004	0.12	0.008	0.13	0.02	0.15
CD (p=0.05)	-	0.199	0.011	0.340	-	0.374	0.051	0.430
Spacing (S)								
s_1: 40 cm x 20 cm	4.85	161.25	62.38	253.88	5.71	219.53	130.38	266.04
s_2: 60 cm x 30 cm	4.80	190.48	88.01	257.56	5.69	232.61	139.03	279.92
SEm±	0.04	0.07	0.004	0.12	0.008	0.13	0.02	0.15
CD (p=0.05)	-	0.199	0.011	0.340	-	0.374	0.051	0.430
Nutrient levels (N) kg NPK ha^{-1}								
n_1: 40:80:40	4.88	183.03	80.39	269.02	5.74	231.78	142.78	290.15
n_2: 30:60:30	4.84	174.47	74.26	253.84	5.70	227.35	133.02	273.34
n_3: 20:40:20	4.75	170.10	70.92	244.29	5.67	219.09	128.32	255.44
SEm±	0.04	0.08	0.01	0.14	0.01	0.16	0.02	0.18
CD (p=0.05)	-	0.244	0.014	0.417	-	0.458	0.062	0.527

Table 3b. Effect of V × S × N interaction on soil pH and available NPK after harvest (kg ha^{-1})

Treatments	First-year				Second year			
	Soil pH	Available N	Available P	Available K	Soil pH	Available N	Available P	Available K
$v_1s_1n_1$	4.91	169.90	65.33	260.05	4.91	228.07	128.58	287.45
$v_1s_1n_2$	4.80	157.81	53.19	252.18	4.80	225.62	118.25	263.16
$v_1s_1n_3$	4.83	157.41	63.72	249.49	4.83	213.07	125.33	240.59
$v_1s_2n_1$	4.88	197.81	84.11	279.55	4.88	238.00	145.60	291.73
$v_1s_2n_2$	4.78	191.54	87.91	244.39	4.78	235.80	131.38	276.63
$v_1s_2n_3$	4.73	187.00	79.33	238.09	4.73	233.27	130.70	264.03
$v_2s_1n_1$	4.93	169.39	72.33	264.67	4.93	220.44	140.78	284.15
$v_2s_1n_2$	4.86	159.00	64.39	252.54	4.86	217.98	131.58	264.50
$v_2s_1n_3$	4.75	154.00	55.31	244.34	4.75	212.00	137.76	256.36
$v_2s_2n_1$	4.80	195.00	99.79	271.82	4.80	240.62	156.16	297.26
$v_2s_2n_2$	4.93	189.54	91.56	266.25	4.93	230.00	150.86	289.08
$v_2s_2n_3$	4.70	182.00	85.33	245.23	4.70	218.00	119.50	260.79
SEm±	0.09	0.17	0.01	0.28	0.09	0.31	0.04	0.36
CD (p=0.05)	-	0.488	0.027	0.834	-	0.915	0.124	1.053

$v_1s_1n_1$ recorded the significantly highest average pod weight (0.43 g pod^{-1}) and $v_2s_2n_3$, the lowest (0.32 g pod^{-1}).

In the second year, the variations were significant and pod weight was maximum in the variety APK 1, the spacing 40 cm × 20 cm and the nutrient level 40:80:40 kg NPK ha^{-1}, the values in APK1 and Vamban (Rg) 3 in combination with s_1 and n_1 remained comparable (0.57 g pod^{-1} and 0.54 g pod^{-1}, respectively)

Number of seeds per pod

The treatments, individually and in combination did not evoke any significant variation in the number of seeds per pod during both years.

100 seed weight

The 100 seed weight was significantly higher in APK 1 in both years (9.04 and 9.15 g respectively) but remained comparable with nutrient levels and spacing. Interaction effects were significant in the first year alone and $v_1s_2n_1$ recorded significantly the highest 100 seed weight (9.63 g).

Among the varieties, APK 1 showed earliness in flowering. Gardner *et al.* (1988) reported that floral induction occurs in response to a specific number of favorable photo induction cycles, and it varies with plant species and varieties. The difference observed in days to 50% flowering between the two varieties is attributed to their inherent characteristics.

Pod weight is a varietal character and among the combinations, narrow spacing and the highest nutrient level were superior consequent to the increased photosynthetic activity and greater translocation of photosynthates from leaves *via* stem to sink site *i.e.* pods as explained by Singh and Yadav (2008). It is also interpreted that the better availability and utilization of the growth resources under wider spacing would have encouraged source development and more pod production per plant which would have impacted individual pod weights.

There were no marked variations in the number of seeds per pod due to varieties, spacing, and nutrient levels during both years of experimentation. Similar reports of the non-significant influence of different spacing and nutrient levels on the number of seeds per pod were outlined by Saig *et al.* (1993) and Telgote *et al.* (2004).

The variety APK 1 recorded the highest 100-seed weight (9.04 and 9.15 g) during both years. The 100-seed weight is mostly regulated by the genetic makeup of the varieties and hence, the management practices of spacing and nutrient levels did not significantly influence these characteristics. This was reflected in the interactions, with the combinations involving APK 1 being superior.

Seed yield

The significant influence of varieties, spacing, and nutrient levels on seed yield was prominent in both years (Tables 2 a and b). The maximum yield was recorded in APK 1 (0.99 and 1.07 t ha^{-1}), 40 cm × 20 cm spacing (1.19 and 1.28 t ha^{-1}) and 40:80:40 kg NPK ha^{-1} (1.06 and 1.11 t ha^{-1}). The trend remained the same for the interactions also. In V × S × N interaction, $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) registered the significantly highest seed yield of 1.36 t ha^{-1} and 1.39 t ha^{-1} during the first and second year respectively, on par with $v_2s_1n_1$ and $v_1s_1n_2$. Seed yield was the lowest in $v_2s_2n_3$ (Vamban (Rg) 3 + 60 cm × 30 cm + 20:40:20 kg NPK ha^{-1}). The results of the pooled analysis also revealed similar trends, with a maximum seed yield of 1.38 t ha^{-1} in $v_1s_1n_1$ interaction on par with $v_2s_1n_1$ (1.33 t ha^{-1}).

Yield is dependent upon the total crop growth and development and is the cumulative expression of different yield attributes (Kaur *et al.* 2015). During both years, individual effects of variety APK 1, spacing 40 cm × 20 cm, and nutrient level 40:80:40 kg NPK ha^{-1} resulted in the significantly highest per hectare seed yields.

The higher seed yield realized in APK 1 compared to Vamban (Rg) 3 is the consequence of the higher in yield contributing attributes including pod length, pod weight, and 100 seed weight recorded in APK 1 which are not solely dependent on management, but on genotype also (Prashanthi *et al.* 2001).

The higher seed yields recorded at narrow spacing despite the superior per-plant performances conform to the findings of Kumar *et al*. (2014) and Goud *et al.* (2016) that attributed to the higher plant density. Yields were nearly 68 % higher at 40 cm × 20 cm than at 60 cm × 30 cm. The crop responded positively to the nutrient doses with the maximum seed yields at the highest level of nutrients (40:80:40 kg NPK ha^{-1}), the values being 11 and 19 % greater than that with 75 and 50 % lower NPK doses, respectively.

Positive responses to inorganic fertilizers have been reported by Patel *et al*. (2010); Reddy *et al.* (2011) and Tiwari *et al.* (2011). Application of the major nutrients (NPK) based on soil test results might have improved the fertility status of the soil ensuring an efficient and balanced nutrient supply system in the soil during the growth stages, leading to better plant growth, and dry matter production thereby positively influencing the yield attributes (Rajesh *et al.* 2017). The superior yields would be due to the higher nutrient demands of the N-fixing crop that could be met with the 40:80:40 kg ha^{-1} dose of NPK. It is interpreted that the application of the chemical fertilizers increased the availability of nutrients (N, P, and K) in soil solution and their utilization by the crop. Soil test-based application as done in the present study, could ensure the availability, eliminating the possibilities of excesses and antagonistic interactions, especially of micronutrients.

Soil properties

During both years, there was an increase in soil pH from the initial value but did not record any marked variations with the treatment factors (Table 3a). An increase in soil nutrient status (NPK) was observed after the harvest of the crop during both years and the variations with the treatments are presented in Table 3a.

The wider spacing (60 cm × 30 cm) and the higher nutrient level (40:80:40 kg NPK ha^{-1}) registered the significantly highest soil available

NPK. Among the varieties, the highest available N was registered in APK 1 grown soil, while P and K were in Vamban (Rg) 3. Available N status in soil remained significantly high for the combinations involving v_1, s_2 and n_1 in interactions in both years. Maximum available P status was observed in interactions involving v_2, s_2 and n_1. For available K, during the first year, the significantly highest available K was observed in interactions of s_2 and n_1 with either of the varieties.

Although soil pH was not found markedly influenced, increases from initial values were recorded with the cultivation of red gram. Plant roots can induce pH changes either by releasing protons (H^+) or hydroxyl ions (OH^-) to maintain ion balance (Hinsinger *et al.* 2003), depending on the nutritional status of the plants. The uptake of anions over cations often causes the roots to secrete HCO_3^- to maintain electrical neutrality, a process that leads to increased rhizosphere pH. Further, the liming done based on soil test data would have contributed to the increase in soil pH. Documented literature also suggests that legumes can lower soil acidity (Sakala *et al*. 2003, Anjaly 2018).

The potential of red gram in improving soil fertility has been elucidated by Adjei-Nsiah (2012). Among the varieties, APK 1 resulted in the significantly highest soil available N, which might be due to comparatively higher root nodulation, which is expected to have contributed to the N in the soil. Phosphorus and K uptake remained higher in APK 1 (11.67 and 13.18 kg ha^{-1} P and 35.13 and 31.51 kg ha^{-1} K during the first and second year respectively) leading to greater depletion of the elements in soil and lower soil status compared to that in Vamban (Rg) 3. Under wider spacing, the plant population was thinner leading to reduced utilization of nutrient reserves in soil.

The higher nutrient dose added more NPK in soil, combined with the N fixing property of red gram, the free N fixers in soil and the solubilization effect of root exudates and microbial activity on insoluble and fixed reserves of P and K in soil would have added to the availability of P and K (Ghosh *et al*. 2007). The authors have elucidated the root exudation of significant amounts of malonic and oxalic acids along with piscidic acid that is specific to the red gram, which can chelate from iron (Fe) ligands and solubilize P. The effects of wider spacing and higher NPK dose ensured the enhanced residual fertility in the post-harvest soil.

Economic analysis

The economics of red gram cultivation computed based on the costs involved and the market price of produce are detailed in Fig. 1. Among the various treatments $v_1s_1n_1$ recorded the highest net return and benefit: cost (B:C) ratio during the first and second year of cultivation, followed by the treatment $v_2s_1n_1$. Combination $v_2s_2n_3$ proved least profitable during both years. Based on the pooled mean values computed for the two years, APK 1 raised at 40 cm × 20 cm with 40:80:40 kg NPK ha^{-1}, was adjudged most economic as it fetched the highest net return (₹ 88621 ha^{-1}) and B: C ratio (2.03), followed by Vamban (Rg) 3 cultivated with the same management practice (₹ 82546 ha^{-1} and 1.96). A spacing of 40 cm × 20 cm and an NPK dose of 40:80:40 kg ha^{-1} was ideal for short-duration red gram varieties.

The study has brought to light the suitability of short-duration red gram varieties, Vamban (Rg) 3 and APK 1 in the humid tropical climate of Kerala. Based on the pooled analysis and economics, it is concluded that APK1 variety, at 40 cm × 20 cm spacing and 40:80:40 NPK kg ha^{-1} can be recommended as the most profitable agronomic package for inclusion of red gram in the agri-food systems and cultivation in southern Kerala.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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