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Effect of integrated nutrient management on nodulation, nutrient uptake and residual soil fertility in rice fallow green gram (*Vigna radiata* L.) ecosystems of Eastern India

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Abstract
A field experiment was carried out during the rabi season of 2017-18 at the Instructional Farm of the Orissa University of Agriculture and Technology, Bhubaneswar, to evaluate the impact of different nutrient management practices on green gram grown under rice fallow conditions. Twelve treatments were tested in a randomized block design with three replications. These included: T_1—recommended dose of fertilizer (RDF) at 20:40:20 N:P_2O_5:K_2O; T_2—2% urea spray at 26 and 36 DAS; T_3—2% DAP spray at 26 and 36 DAS; T_4—2% NPK (19:19:19) spray at 26 and 36 DAS; T_5—T_1 + 2% urea spray at 26 DAS; T_6—T_1 + 2% DAP spray at 26 DAS; T_7—T_1 + 2% NPK (19:19:19) spray at 26 DAS; T_8—T_1 + T_2; T_9—T_1 + T_3; T_{10}—T_1 + T_4; T_{11}—T_1 + water spray at 26 and 36 DAS; and T_{12}—absolute control. The soil at the site was sandy loam, slightly acidic (pH 5.23), low in available nitrogen, medium in phosphorus, and high in potassium. The green gram variety IPM 02-14 was grown using recommended agronomic practices.
Results showed that the highest number of root nodules occurred with the application of RDF as basal fertilizer along with a 2% NPK (19:19:19) spray at 26 and 36 DAS. The greatest nutrient uptake (57.94 kg N ha^{-1}, 5.51 kg P ha^{-1}, and 36.50 kg K ha^{-1}) was also observed under this treatment. Residual soil nutrient status improved slightly, with available nitrogen and potassium increasing to 195.8 and 303.8 kg ha^{-1}, respectively, under the same treatment. The highest available phosphorus (29.3 kg ha^{-1}) was recorded in the treatment receiving RDF as basal plus two sprays of 2% DAP, compared to initial soil levels of 182.1 kg N ha^{-1}, 16.2 kg P_2O_5 ha^{-1}, and 298.4 kg K_2O ha^{-1}.

Keywords: Rice fallow, foliar nutrition, nodules

1. Introduction
Medicinal plants have greatly gained importance in the management and treatment of human diseases, globally [1]. It constitutes the main source of primary healthcare in most rural populations, especially in many African countries, due to its affordability and availability. However, as the usage of these medicinal plants becomes more widespread around the world, there are questions and misgivings about the quality, efficacy, and safety of the products utilized in the health sector [2, 3, 4]. These concerns have hampered the sensible use and validation of bio-products derived from these herbs for the treatment and management of disorders [5].
The validation and quality assurance of medicinal plant products has been hampered by a lack of or incorrect plant identification.
The correct identification of the starting material is a must for assuring the reproducible quality of herbal medicine, which is imPulses hold an important position in India, especially for people who follow a vegetarian diet, as they are an excellent source of protein. Their lysine-rich protein helps compensate for the amino acid deficiency commonly found in cereal-based diets, making their nutritional quality comparable to that of milk protein. Because of their high protein value, pulses are often referred to as the "poor man's meat." They also provide essential vitamins such as riboflavin, thiamine, niacin, and iron. Additionally, dietary fibre present in pulses is recommended for good health. On average, pulses contain 18-24% protein along with significant amounts of calcium and phosphorus. Beyond their nutritional value, pulses enrich soil fertility through biological nitrogen

fixation, making them critical for sustainable agriculture (Kanniyan, 1999). In India, pulse crops are mainly cultivated under rainfed conditions on low-fertility soils. Considering the growing population and widespread malnutrition, pulse yields need substantial improvement.

A balanced diet requires the inclusion of all essential food groups. According to FAO/WHO, an adult needs about 85 grams of pulses per day to meet basic protein requirements. However, per capita availability of pulses in India has fluctuated, dropping from 70.3 g/day in 1956 to 37.5 g/day in 1981, and further to 29.1 g/day in 2003. Due to improved production, government support, and increased imports, availability has gradually risen to 47.2 g/day (GoI, 2016), though it still falls short of the recommended 50 g/day.

The Indian Institute of Pulses Research (IIPR), Kanpur, estimates that national pulse demand will reach 39 million tonnes by 2050, requiring a 2.2% annual growth rate in production (IIPR, 2015). Meeting this demand will require both higher productivity and expansion of pulse cultivation through improved technologies.

One promising approach is the effective use of rice fallows to grow short-duration pulses such as green gram, black gram, and cowpea. Odisha falls under a low-productivity zone (<600 kg/ha), where yields could be significantly enhanced by addressing major production challenges. Since green gram grown in rice fallows must rely on residual soil moisture and nutrients and complete its life cycle within 60-70 days, yields are often low and variable (300-500 kg/ha). Major constraints include poor seed quality, low germination, moisture stress during flowering, lack of fertilizer use, absence of foliar sprays, and inadequate weed management. Of these, insufficient nutrient application is a key factor limiting yields. Although nutrient management has been well studied under irrigated conditions, research on nutrient management in rice fallow green gram remains limited.

Currently, foliar spraying is the most effective method to overcome nutrient stress and improve yields in rice fallow ecosystems. Foliar nutrition allows for rapid and efficient nutrient uptake, minimizes nutrient losses, and helps regulate plant nutrient absorption (Manonmani & Srimathi, 2009). Applying essential nutrients through foliar sprays promotes root growth, nodulation, energy transfer, metabolic activity, nutrient translocation, pod formation, and early maturity, ultimately contributing to higher pulse productivity.

2. Materials and Methods

1.1 Experimental Site and Design

The experiment was conducted during the rabi season of 2017-18 at the Instructional Farm, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar. The site is located at 20°15' N latitude and 85°52' E longitude, 25.9 m above mean sea level, and approximately 64 km from the Bay of Bengal. It falls under the East and Southeastern Coastal Plain Agroclimatic Zone of Odisha.

A randomized block design with three replications and twelve treatments was used for the study. Each gross plot measured 5.65 m × 5.3 m, while the net plot area was 5.0 m × 5.0 m, with a plant spacing of 30 cm × 10 cm.

1.2 Soil Characteristics

The soil at the experimental site was sandy loam with a slightly acidic pH of 5.23. It was low in available nitrogen (182.1 kg ha^{-1}), medium in available phosphorus (16.2 kg P_2O_5 ha^{-1}), and high in available potassium (298.4 kg K_2O ha^{-1}).

1.3 Treatments and Crop Management

The treatments comprised different combinations of basal fertilization and foliar nutrient application:

- T_1: Recommended fertilizer dose (RDF) @ 20:40:20 N:P_2O_5:K_2O kg ha^{-1}
- T_2: 2% Urea spray at 26 and 36 DAS
- T_3: 2% DAP spray at 26 and 36 DAS
- T_4: 2% NPK (19:19:19) spray at 26 and 36 DAS
- T_5: T_1 + 2% Urea spray at 26 DAS
- T_6: T_1 + 2% DAP spray at 26 DAS
- T_7: T_1 + 2% NPK (19:19:19) spray at 26 DAS
- T_8: T_1 + T_2
- T_9: T_1 + T_3
- T_{10}: T_1 + T_4
- T_{11}: T_1 + Water spray at 26 and 36 DAS
- T_{12}: Control (no fertilizer)

The green gram variety IPM 02-14 was planted on December 17, 2017, using a seed rate of 20 kg ha^{-1}. Basal nutrients were supplied according to the treatments using urea, di-ammonium phosphate (DAP), and muriate of potash (MOP). Foliar sprays were applied with a hand sprayer fitted with a conical nozzle at the pre-flowering stage (26 DAS) and again 10 days later (36 DAS).

2. Experimental observations

2.1 Root nodules per plant (no.) and fresh weight (mg)

In each plot, root nodules were counted on five randomly selected plants at 15, 30, and 45 DAS. The plants were carefully uprooted, the roots were washed, and the nodules were separated, counted, weighed, and recorded.

2.2 Soil analysis

Soil samples from each treatment were collected at a depth of 0-15 cm. Samples from the corresponding treatments in each replication were combined to form composite samples, which were then shade-dried, finely ground, and sieved through a 2 mm mesh for chemical analysis.

2.3 Plant analysis

2.3.1 Nutrient content

At harvest, plant samples were randomly collected and analyzed for nitrogen, phosphorus, and potassium content in both the seed and haulm. For each treatment, a composite sample was prepared from the three replications. The oven-dried samples were finely ground and subjected to nutrient analysis using standard procedures. Total nitrogen was estimated using the modified Micro-Kjeldahl distillation method (Jackson, 1973) after digesting 0.1 g of oven-dried (70 °C) haulm and 0.2 g of dried seed. Phosphorus and potassium contents were determined by digesting 0.1 g of straw and 0.2 g of grain with nitric acid (HNO_3) and perchloric acid ($HClO_3$), filtering, and diluting the digest to a standard volume. Phosphorus was measured using a spectrophotometer, while potassium was estimated with a flame photometer (Jackson, 1973).

2.3.2 Nutrient uptake

The nutrient concentrations in the seed and haulm, determined from plant analysis, were multiplied by their respective yields to calculate nutrient uptake expressed in kg ha^{-1}.

Uptake (kg ha^{-1}) = Nutrient content (%) X Yield (kgha^{-1})/100

2.4 Statistical analysis

All biometric observations recorded before and after harvest were tabulated and analyzed statistically following the standard procedures for a Randomized Block Design (RBD). Analysis of variance (ANOVA) was performed, and treatment differences were tested for significance using the F-test. The standard error of the mean [SE(m) ±] and the critical difference (CD) at the 5% level of probability were calculated using the methods outlined by Gomez and Gomez (1984) for result interpretation.

3. Experimental Findings

3.1 Root nodules plant^{-1}

The number of root nodules per plant was measured at each growth stage, and the pattern of nodule formation is presented in Table 1.

Table 1: Number of nodules per plant of green gram at different stages as influenced by nutrient management practices

Treatment	Days after sowing			Harvest
	15	30	45	
T_1 : RDF(20:40:20 kg $N:P_2O_5:K_2O$ ha^{-1}) as basal	1.20	7.65	9.73	3.33
T_2 : Urea @ 2% at 26 and 36 DAS	0.47	7.45	9.43	3.27
T_3: DAP @ 2% at 26 and 36 DAS	0.53	7.53	9.33	3.07
T_4: 19:19:19(NPK) @ 2% at 26 DAS	0.47	7.47	9.47	3.27
T_5: RDF + Urea @ 2% at 26 DAS	1.40	7.80	10.03	3.40
T_6: RDF + DAP @ 2% at 26 DAS	1.20	7.87	10.17	3.47
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	1.33	7.92	10.27	3.53
T_8: RDF + Urea @ 2% at 26 and 36 DAS	1.47	7.95	10.37	3.47
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	1.87	8.10	10.83	3.60
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	1.40	8.67	11.47	3.93
T_{11}: RDF+ water spray	1.47	7.77	9.93	3.57
T_{12}: Absolute control	0.47	3.57	4.47	1.80
S.Em ±	0.19	0.14	0.18	0.15
CD (P = 0.05)	0.56	0.40	0.52	0.44

The number of root nodules per plant reached its peak at 45 days after sowing. At this stage, the highest nodule count (11.47 per plant) was obtained with the treatment involving basal application of RDF along with a 2% NPK (19:19:19) spray at 26 and 36 DAS (T_{10}).

As shown in Table 1, the treatment receiving RDF as basal and a 2% DAP spray at 26 and 36 DAS (T_9) produced the highest number of nodules (1.87) at 15 DAS. However, at both 30 and 45 DAS, the maximum nodule count (8.77 and 11.47, respectively) was recorded under the treatment with RDF as basal plus NPK (19:19:19) spray at 2% at 26 and 36 DAS (T_{10}), which was significantly superior to all other treatments. The lowest number of nodules (4.47 per plant) at 45 DAS was observed in the control (T_{12}).

3.2 Nodule fresh weight (mg plant-^{1})

Fresh weight of root nodules was measured at 15, 30, and 45 DAS, and the corresponding data are presented in Table 2.

Table 2: Fresh weight of nodules (mg plant^{-1}) of green gram at different stages as influenced by nutrient management practices

Treatment	Days after sowing			Harvest
	15	30	45	
T_1 : RDF(20:40:20 kg $N:P_2O_5:K_2O$ ha^{-1}) as basal	5.60	87.70	157.33	37.40
T_2 : Urea @ 2% at 26 and 36 DAS	1.87	86.47	154.17	35.83
T_3: DAP @ 2% at 26 and 36 DAS	3.20	85.54	152.73	35.67
T_4: 19:19:19(NPK) @ 2% at 26 DAS	1.90	86.10	153.87	36.07
T_5: RDF + Urea @ 2% at 26 DAS	7.33	96.70	161.37	51.00
T_6: RDF + DAP @ 2% at 26 DAS	8.20	97.77	163.37	49.90
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	7.73	98.20	162.97	51.43
T_8: RDF + Urea @ 2% at 26 and 36 DAS	7.87	99.70	162.80	52.13
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	7.73	107.17	167.50	56.60
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	7.77	112.57	171.83	59.03
T_{11}: RDF+ water spray	7.83	91.13	157.97	38.90
T_{12}: Absolute control	1.60	61.99	74.00	22.43
S.Em ±	0.52	3.37	3.07	1.93
CD (P = 0.05)	1.52	9.89	9.00	5.65

The heaviest root nodules were observed in plants receiving the recommended dose of fertilizer at sowing along with 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}). This was closely followed by plants treated with RDF plus two sprays of 2% DAP at 26 and 36 DAS (T_9) at 30 DAS. At 45 DAS, relatively heavier nodules were also recorded in plants receiving RDF with either one or two DAP sprays (T_6 and T_9) or a single NPK spray at 26 DAS (T_7). The lowest nodule fresh weight per plant (74 mg) was recorded in the control treatment (T_{12}).

3.3. Nutrient content and up take

The nutrient content and uptake data are presented in Tables 3.1, 3.2, and 3.3.

3.3.1 Nitrogen

The highest nitrogen content in both grain (3.35%) and haulm (2.16%) was recorded in the treatment receiving RDF as basal along with 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), while the lowest nitrogen content in grain (3.25%) and haulm (2.09%) was observed in the control treatment (T_{12}).

Table 3.1: Nitrogen content (%) and uptake (kg/ha) of green gram as influenced by nutrient management practices

Treatment	Nitrogen Content (%)		Nitrogen up take (kg ha^{-1})		
	Seed	Haulm	Seed	Haulm	Total
T_1 : RDF(20:40:20 kg $N:P_2O_5:K_2O$ ha^{-1}) as basal	3.27	2.13	15.37	29.05	44.43
T_2 : Urea @ 2% at 26 and 36 DAS	3.26	2.13	14.67	28.42	43.09
T_3: DAP @ 2% at 26 and 36 DAS	3.26	2.13	14.82	28.60	43.42
T_4: 19:19:19(NPK) @ 2% at 26 DAS	3.28	2.13	15.17	28.70	43.87
T_5: RDF + Urea @ 2% at 26 DAS	3.29	2.14	20.21	32.39	52.60
T_6: RDF + DAP @ 2% at 26 DAS	3.31	2.14	20.47	32.69	53.16
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	3.32	2.15	21.05	33.33	54.38
T_8: RDF + Urea @ 2% at 26 and 36 DAS	3.34	2.15	21.47	33.67	55.14
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	3.33	2.16	22.02	34.66	56.68
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	3.35	2.16	22.63	35.31	57.94
T_{11}: RDF+ water spray	3.28	2.14	17.16	29.62	46.79
T_{12}: Absolute control	3.25	2.09	9.43	20.52	29.95
S.Em ±	0.02	0.02	0.36	0.83	0.95
CD (P = 0.05)	0.04	0.05	1.05	2.42	2.78

Nitrogen uptake was highest in the treatment with RDF as basal and 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), with values of 22.63 kg ha^{-1} in seed, 35.31 kg ha^{-1} in haulm, and 57.94 kg ha^{-1} for the total plant. This was statistically comparable with T_9 and T_8 for seed uptake, T_9, T_8, and T_7 for haulm uptake, and T_9 for total nitrogen uptake. The lowest nitrogen uptake was observed in the control (T_{12}), with 9.43 kg ha^{-1} in seed, 20.52 kg ha^{-1} in haulm, and 29.95 kg ha^{-1} for the total plant.

3.3.2 Phosphorous

The highest phosphorus content in both seed (0.39%) and haulm (0.17%) was observed in the treatment with RDF as basal and 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), which was superior to all other treatments except T_9 and T_8. The lowest phosphorus content in seed (0.33%) and haulm (0.14%) was recorded in the control treatment (T_{12}).

Table 3.2: Phosphorous content (%) and uptake (kg ha^{-1}) of green gram as influenced by nutrient management practices

Treatment	Phosphorous Content (%)		Phosphorous up take (kg ha^{-1})		
	Seed	Haulm	Seed	Haulm	Total
T_1 : RDF(20:40:20 kg $N:P_2O_5:K_2O$/ha) as basal	0.35	0.14	1.63	1.96	3.59
T_2 : Urea @ 2% at 26 and 36 DAS	0.34	0.14	1.51	1.89	3.40
T_3: DAP @ 2% at 26 and 36 DAS	0.35	0.14	1.57	1.92	3.49
T_4: 19:19:19(NPK) @ 2% at 26 DAS	0.34	0.14	1.58	1.93	3.52
T_5: RDF + Urea @ 2% at 26 DAS	0.36	0.15	2.18	2.22	4.41
T_6: RDF + DAP @ 2% at 26 DAS	0.36	0.15	2.23	2.26	4.49
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	0.37	0.15	2.33	2.29	4.62
T_8: RDF + Urea @ 2% at 26 and 36 DAS	0.38	0.16	2.42	2.42	4.84
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	0.38	0.16	2.54	2.53	5.06
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	0.39	0.17	2.66	2.85	5.51
T_{11}: RDF+ water spray	0.35	0.15	1.84	2.03	3.87
T_{12}: Absolute control	0.33	0.14	0.96	1.39	2.35
S.Em ±	0.00	0.00	0.05	0.06	0.10
CD (P = 0.05)	0.01	0.01	0.15	0.18	0.30

Phosphorus uptake was highest in the treatment with RDF as basal and 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), with values of 2.66 kg ha^{-1} in grain, 2.85 kg ha^{-1} in haulm, and 5.51 kg ha^{-1} for the total plant. Seed phosphorus uptake in this treatment was statistically at par with T_9 and significantly higher than all other treatments. The lowest phosphorus uptake was recorded in the control (T_{12}), with 0.96 kg ha^{-1} in seed, 1.39 kg ha^{-1} in haulm, and 2.35 kg ha^{-1} for the total plant.

3.3.3 Potassium

The highest potassium content in both grain (0.68%) and haulm (1.95%) was recorded in the treatment receiving RDF as basal along with 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}). The lowest potassium content in seed (0.57%) and haulm (1.83%) was observed in the control treatment (T_{12}).

Potassium uptake was highest in the treatment with RDF as basal and 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), with values of 4.57 kg ha^{-1} in seed, 31.93 kg ha^{-1} in haulm, and 36.50 kg ha^{-1} for the total plant. This treatment was statistically at par with T_9 for seed uptake, T_9 and T_8 for haulm uptake, and T_9 for total potassium uptake. The lowest uptake was recorded in the control (T_{12}), with 9.43 kg ha^{-1} in seed, 20.52 kg ha^{-1} in haulm, and 29.95 kg ha^{-1} for the total plant.

Table 3.3: Potassium content (%) and uptake (kg ha^{-1}) of green gram as influenced by nutrient management practices

Treatment	Potassium content (%)		Potassium up take (kg ha^{-1})		
	Seed	Haulm	Seed	Haulm	Total
T_1 : RDF(20:40:20 kg N:P_2O_5:K_2O kg ha^{-1}) as basal	0.58	1.84	2.74	25.06	27.80
T_2 : Urea @ 2% at 26 and 36 DAS	0.58	1.81	2.61	24.27	26.87
T_3: DAP @ 2% at 26 and 36 DAS	0.57	1.83	2.61	24.57	27.18
T_4: 19:19:19(NPK) @ 2% at 26 DAS	0.58	1.83	2.69	24.73	27.42
T_5: RDF + Urea @ 2% at 26 DAS	0.61	1.87	3.72	28.25	31.97
T_6: RDF + DAP @ 2% at 26 DAS	0.62	1.88	3.81	28.74	32.55
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	0.63	1.90	3.97	29.37	33.34
T_8: RDF + Urea @ 2% at 26 and 36 DAS	0.63	1.91	4.03	29.91	33.94
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	0.64	1.92	4.21	30.89	35.09
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	0.68	1.95	4.57	31.93	36.50
T_{11}: RDF+ water spray	0.59	1.89	3.10	26.09	29.19
T_{12}: Absolute control	0.57	1.83	1.66	17.96	19.62
S.Em ±	0.01	0.01	0.10	0.80	0.80
CD (P = 0.05)	0.02	0.04	0.28	2.34	2.35

3.4. Residual soil fertility status of soil

The treatment-wise residual soil fertility status is presented in Table 4. The data indicate that the highest residual nitrogen and potassium (195.8 and 303.8 kg ha^{-1}, respectively) were recorded in the treatment with RDF as basal and 2% NPK (19:19:19) foliar sprays at 26 and 36 DAS (T_{10}), which was statistically at par with T_9, T_8, T_7, and T_6. The highest residual phosphorus (P_2O_5) was observed in the treatment receiving RDF as basal and two sprays of 2% DAP at 26 and 36 DAS, closely followed by RDF with either 2% NPK or urea sprays at 26 and 36 DAS. The lowest residual nutrient levels (160.2, 14.3, and 284.4 kg ha^{-1} of N, P_2O_5, and K_2O, respectively) were recorded in the control treatment (T_{12}).

Table 4: Residual soil fertility(N:P_2O_5:K_2O) status (kg ha^{-1}) of green gram as influenced by nutrient management practices

Treatment	N kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}
T_1 : RDF(20:40:20 kg N:P_2O_5:K_2O/ha) as basal	187.3	23.7	299.6
T_2 : Urea @ 2% at 26 and 36 DAS	172.1	18.3	290.7
T_3: DAP @ 2% at 26 and 36 DAS	171.7	19.4	289.8
T_4: 19:19:19(NPK) @ 2% at 26 DAS	170.8	18.6	292.0
T_5: RDF + Urea @ 2% at 26 DAS	189.4	25.2	289.5
T_6: RDF + DAP @ 2% at 26 DAS	191.2	26.8	299.2
T_7: RDF + 19:19:19(NPK) @ 2% at 26 DAS	192.1	25.9	301.4
T_8: RDF + Urea @ 2% at 26 and 36 DAS	193.4	27.2	301.8
T_9 : RDF + DAP @ 2% at 26 and 36 DAS	194.2	29.3	300.6
T_{10}:RDF+19:19:19(NPK) @ 2% at 26 and 36 DAS	195.8	28.4	303.8
T_{11}: RDF+ water spray	183.6	24.3	289.4
T_{12}: Absolute control	160.2	14.3	284.4
S.Em ±	1.8	0.9	3.5
CD (P = 0.05)	5.3	2.7	10.2

Initial soil status: 182.1 N 16.2 P_2O_5 298.4 K_2O

4. Discussion

4.1 Number and fresh weight of root nodules (mg)

The highest number of root nodules and fresh weight per plant were recorded at 45 DAS. Root nodule development was significantly influenced by different foliar nutrient treatments. The maximum number of nodules was observed with the application of RDF as basal combined with 2% NPK (19:19:19) sprays at 26 and 36 DAS. This effect is likely due to the improved root growth and enhanced rhizobial activity in the rhizosphere stimulated by nitrogen, phosphorus, and potassium supplied through basal and foliar nutrition, leading to the formation of a greater number of active nodules. These findings are consistent with the observations of Kumar *et al.* (2018).

4.2 Nutrient content and uptake

The application of foliar nutrients along with RDF as basal significantly enhanced nitrogen, phosphorus, and potassium content in both seed and haulm compared to the control, likely due to more efficient nutrient absorption through the foliage than the roots.

In this study, nitrogen content in both seed and haulm was highest with RDF as basal combined with 2% NPK (19:19:19) sprays at 26 and 36 DAS, followed closely by RDF as basal with two foliar sprays of 2% DAP or urea. The increased nitrogen uptake may be attributed to greater nitrogen availability, higher biomass production, increased nodule formation, enhanced yield, and delayed chlorophyll and leaf nitrogen loss, which promoted photosynthesis.

Similarly, phosphorus and potassium content in seed and haulm were generally highest under the treatment with RDF as basal plus two 2% NPK foliar sprays at 26 and 36 DAS, and were at par with RDF as basal combined with two 2% DAP foliar sprays. The improved P and K uptake may be due to greater dry matter accumulation and increased availability of soil nutrients supplemented by foliar feeding. These results are in agreement with the findings of Suhathiya and Ravichandran (2017), Shashikumar *et al.* (2013), and Geetha and Velayutham (2009).

4.3 Residual soil fertility status
The data on residual soil fertility indicated that the highest residual nitrogen and potassium (195.8 and 303.8 kg ha^{-1}, respectively) were recorded in the treatment receiving RDF as basal along with 2% NPK (19:19:19) sprays at 26 and 36 DAS. This was statistically at par with treatments receiving RDF plus two sprays of 2% DAP or urea, as well as RDF combined with a single spray of 2% NPK or DAP. The highest residual phosphorus (P_2O_5) was observed in the treatment with RDF as basal and two 2% DAP foliar sprays at 26 and 36 DAS, closely followed by RDF with 2% NPK or urea sprays at the same stages.

The increased residual nitrogen in the soil may be attributed to enhanced nodule formation. Higher levels of available N, P_2O_5, and K_2O could be due to greater nutrient application and the increased number of nodules per plant, which fixed more nitrogen. These findings are consistent with those reported by Bansal and Ahmad (2015) in green gram and Shashikumar *et al.* (2013) in black gram.

5. Summary and Conclusion
A field experiment was carried out to evaluate the effect of nutrient management on green gram (Vigna radiata L.) grown in rice fallows at the Instructional Farm of Orissa University of Agriculture and Technology, Bhubaneswar during the rabi season of 2017-18. Twelve treatments were tested: T_1—RDF @ 20:40:20 ($N:P_2O_5:K_2O$); T_2—2% urea spray at 26 and 36 DAS; T_3—2% DAP spray at 26 and 36 DAS; T_4—2% NPK (19:19:19) spray at 26 and 36 DAS; T_5—T_1 + 2% urea spray at 26 DAS; T_6—T_1 + 2% DAP spray at 26 DAS; T_7—T_1 + 2% NPK (19:19:19) spray at 26 DAS; T_8—T_1 + T_2; T_9—T_1 + T_3; T_{10}—T_1 + T_4; T_{11}—T_1 + water spray at 26 and 36 DAS; and T_{12}—absolute control. The experiment was laid out in a randomized block design with three replications. The soil was sandy loam, slightly acidic (pH 5.23), low in available nitrogen (182.1 kg/ha), medium in phosphorus (16.2 kg P_2O_5/ha), and high in potassium (298.4 kg K_2O/ha). The green gram variety IPM 02-14 was sown on 17 December 2017 and harvested on 18 February 2018.

5.1 Summary
1. The maximum number of root nodules (11.47 per plant) and fresh weight of nodules (171.8 mg per plant) were recorded at 45 DAS with the application of RDF as basal combined with 2% NPK (19:19:19) sprays at 26 and 36 DAS. These parameters were significantly influenced by the different treatments.
2. Nutrient content and uptake in both seed and haulm were significantly higher with RDF as basal plus 2% NPK (19:19:19) sprays at 26 and 36 DAS. This treatment recorded the highest nitrogen (22.6 and 35.3 kg/ha), phosphorus (2.7 and 2.8 kg/ha), and potassium (4.57 and 31.93 kg/ha) in seed and haulm, respectively, while the lowest uptake was observed in the control.
3. Residual soil fertility was also highest under RDF as basal plus 2% NPK (19:19:19) sprays at 26 and 36 DAS, with 195.8 kg N/ha and 303.8 kg K_2O/ha, whereas residual phosphorus (P_2O_5) was highest (29.3 kg/ha) with RDF as basal combined with 2% DAP sprays at 26 and 36 DAS.

5.2 Conclusion
The study indicated that RDF combined with two 2% NPK foliar sprays and RDF combined with two 2% DAP foliar sprays resulted in substantial nutrient removal—57.94, 5.51, and 36.50 kg/ha of N, P, and K; and 56.68, 5.06, and 35.09 kg/ha of N, P, and K, respectively—while leaving residual soil nutrients of 195.8, 28.4, and 303.8 kg/ha and 194.2, 29.3, and 300.6 kg/ha of N, P_2O_5, and K_2O, respectively.

6. Suggestions for further work
It is recommended that this experiment be conducted for at least three years to validate and confirm the present findings.

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