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Effect of sulphur fertilization, humic acid and biofertilizers on soil nutrient status and yield of rajma (*Phaseolus vulgaris* L.)

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Abstract

A field experiment was carried out to study “Studies on effect of sulphur fertilization, humic acid and biofertilizers on soil nutrient status of rajma (*Phaseolus vulgaris* L.)” cultivar Phule Rajma during *rabi* season of the year 2024-2025 at departmental farm of Soil Science, College of Agriculture, Badnapur. The experiment was laid in randomized block design with three replications and seven treatments viz., T₁: 100% RDF (60:80:00 NPK kg/ ha), T₂: 100% RDF+ 25 kg Sulphur ha⁻¹, T₃: 100% RDF + 25 kg ZnSO₄ ha⁻¹, T₄: 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.*, T₅: 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos*, T₆: 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹, T₇: 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. The study showed that the application of sulphur, humic acid, biofertilizers affected on yield and soil nutrient status of rajma. The availability of organic Carbon, macro nutrients N, P, K, S, DTPA micronutrients Zn, Fe, Cu, Mn and Grain and straw yield significantly higher with application treatment T₆ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ and at par with treatment T₇: 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ and the least values are recorded in treatment T₁ 100% RDF. However, the soil chemical properties like pH, EC, CaCO₃, showed non-significant results as compared to properties.

Keywords: sulphur, humic acid, biofertilizers, sulphur oxidizing bacteria and *Rhizophos*

1. Introduction

French bean (*Phaseolus vulgaris* L.), also known as rajmash, common bean, dry bean, pinto bean, field bean, navy bean, and kidney bean, is a leading pulse crop globally. It is newly introduced as non-traditional winter pulse crop in India with high output potential of 2.5-3.5 t/ha (Kumar *et al.* 2020) [17]. French bean originated as a wild vine that grew in the middle American and Andean mountains over 7,000-8,000 years. It comes from Central and South America and is a member of the Leguminosae family (Swiader *et al.* 1992) [22]. In the north eastern Indian plains, it is better suited as a winter crop (*Rabi*). In India, it is produced on around one lakh hectares (ha) in states like Maharashtra, Jammu and Kashmir Himachal Pradesh, Uttarakhand, Tamil Nadu, Kerala, Karnataka, West Bengal, Gujarat. Bihar. Karnataka, Jharkhand. Andhra Pradesh, Odisha. Uttar Pradesh. Madhya Pradesh. (Yadav *et al.* 2022) [24].

Sulphur is 4th major element, essential for plant growth and development. Its requirement is high in oilseed and legume crops, but is mostly considered as a forgotten secondary nutrient in crop production (Bharathi and Poongothai, 2008) [4]. Sulphur is found in various amino acids (cysteine and methionine), oligopeptides (glutathione and phytochelatins), vitamins and cofactors (biotin, thiamine, CoA and S-adenosyl-Met), and a variety of secondary products (Leustek, 2000) [11]. Further, it helps in many metabolic and enzymatic processes like photosynthesis, respiration and symbiotic nitrogen fixation. Sulphur can be used as a nutrient and an acidifier. The acidity produced during sulphur oxidation enhances the availability of other macronutrients like P, Mg, Ca and SO₄ in soils (Linder Mann *et al.* 1991) [12]. The role of sulphur oxidizing bacteria is oxidation of sulphur in soil. Sulphur oxidation is the most important

step of sulphur cycle, which improves soil fertility. These Thiobacillus isolates can be incorporated to enhance sulphur oxidation in soil and to increase soil available sulphate. The role of sulphur oxidizing bacteria is oxidation of sulphur in soil. Sulphur oxidation is the most important step of sulphur cycle, which improves soil fertility. These Thiobacillus isolates can be incorporated to enhance sulphur oxidation in soil and to increase soil available sulphate. (Vidyalakshmi *et al.* 2007) [23].

Humic acid significantly improves plant growth and productivity. This group of compounds helps crops absorb both nutrients and water, resulting in a large rise in productivity. Commercial humic acid compounds improves soil fertility and supply of nutrients, resulting in better plant growth and yield. Furthermore, humic acid is very good at counteracting the detrimental effects of salt stress. (Bahjat *et al.* 2023) [1]. Additionally, it supports soil microorganisms and improves membrane permeability, nutrient absorption, chlorophyll production, photosynthesis, hormone stimulation and enzyme activity. It optimizes soil physical properties for improved root growth and easier water and nutrient absorption. (Bahrun *et al.* 2019) [2].

2. Materials and Methods

2.1 Experiment Site

A field experiment was carried out at departmental farm of Soil Science, College of Agriculture, Badnapur during *rabi* season of the year 2024-2025. Located between above mean sea level at 19° 50' latitudes and 47° 53' longitudes and 409 m meters above sea level.

2.2 Experiment Details

The experiment was laid in randomized block design with three replications and seven treatments viz., T₁: 100% RDF (60:80:00 NPK kg ha⁻¹), T₂: 100% RDF + 25 kg Sulphur ha⁻¹, T₃: 100% RDF + 25 kg ZnSO₄ ha⁻¹, T₄: 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.*, T₅: 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.*, T₆: 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.* + 10 kg humic acid ha⁻¹, T₇: 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.* + 10 kg humic acid ha⁻¹.

2.3 Analysis of soil samples: The soil was analysis characterized for parameters such as pH, electrical conductivity, total nutrients (N, P, K, S), DTPA extractable micronutrients.

Available nitrogen was determined by modified Kjeldhal 's method (Jackson, 1973) [8]. Available phosphorus was determined by Olsen 's method (Jackson, 1973) [8]. Available potassium was determined by 1 N ammonium acetate (pH 7.0) method (Jackson, 1967) [7]. Available Sulphur was determined by turbidity method (Jackson, 1973) [8]. DTPA (0.005 M) extractable Fe, Mn, Zn and Cu will be determined as per the procedure outlined by Lindsay and Norvell (1978) [13] by using atomic absorption spectrophotometer. Grain yield per net plot was recorded after drying the seed. The plot yield was later on converted into kg ha⁻¹ by multiplying it by conversion factor. The straw yield per plot was obtained by subtracting grain yield from bundle weight of each plot. This was later converted into kg ha⁻¹ by conversion factor.

3. Results and Discussion

3.1 Chemical properties of soil

The chemical properties of soil including pH, Electrical conductivity, organic carbon and calcium carbonate - serve as fundamental indicators of soil quality and its ability to sustain plant growth. These factors regulate the availability of essential nutrients, directly influencing soil fertility and the effectiveness of fertilizers and soil amendments. The resulting data is documented in Table 1. At the commencement of the experimental field, the average soil pH, electrical conductivity (EC), soil organic carbon (OC) and calcium carbonate (CaCO₃) were recorded as 7.6, 0.21 dSm⁻¹, 4.5 g kg⁻¹ and 3.7%, respectively. However, The study recorded a significantly higher level 5.07 g kg⁻¹ of organic carbon in treatment T₆ RDF + sulphur @ 25 kg/ ha + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.* + humic acid @ 10 kg ha⁻¹ which was statistically at par with all other treatments T₇ 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.* + 10 kg humic acid ha⁻¹ (5.03) and T₄ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos.* (4.90 g kg⁻¹). And least value 4.5 g kg⁻¹ recorded in treatment T₁ 100% RDF. Meanwhile, no significant changes were recorded in soil pH, electrical conductivity and CaCO₃ during the crop season of rajma.

Nithila *et al.* (2013) [18] found that application of humic acid changed soil properties, leading to increased crop yield by enhancing organic matter and carbon content. Humic acid serves as an energy source for soil microorganisms, stimulating their activity and enhancing the breakdown of organic materials, ultimately contributing to the formation of stable humus and soil organic carbon.

Table 1: Effect of Sulphur fertilization, humic acid and biofertilizers application on chemical properties of soil after harvest of Rajma.

Treatments	Chemical properties			
	pH	EC (dSm ⁻¹)	OC (g kg ⁻¹)	CaCO ₃ (%)
T ₁ 100% RDF	7.6	0.22	4.77	3.97
T ₂ 100% RDF + 25 kg Sulphur ha ⁻¹	7.60	0.23	4.87	4.13
T ₃ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹	7.60	0.23	4.80	3.70
T ₄ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos.</i>	7.67	0.23	4.90	4.00
T ₅ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos.</i>	7.67	0.23	4.83	3.93
T ₆ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos.</i> + 10 kg humic acid ha ⁻¹ .	7.60	0.23	5.07	4.23
T ₇ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos.</i> + 10 kg humic acid ha ⁻¹ .	7.63	0.23	5.03	3.90
SE(m) ±	0.03	0.00	0.06	0.18
CD at 5%	NS	NS	0.19	NS
Before sowing/ Initial soil status	7.6	0.21	4.5	3.70

3.2 Nutrient status of soil

The nutrient status of soil is a fundamental determinant of its fertility, directly influencing crop growth, productivity, and sustainability. Essential macronutrients such as nitrogen (N), phosphorus (P), Potassium (K), and Sulphur (S) play a crucial role in plant development, while micronutrients like iron (Fe), Zinc (Zn), Copper (Cu) and Manganese (Mn) supports various physiological and biochemical processes. A comprehensive assessment of soil nutrient status is essential for site specific nutrient recommendations, ensuring both agricultural productivity and environmental sustainability.

3.3 Available Nitrogen, Phosphorus, Potassium and Sulphur

The information regarding effect of soil application of Sulphur fertilization, humic acid and biofertilizers on available soil nitrogen, phosphorus, potassium, sulphur (kg ha⁻¹) in soil after harvest of rajma is presented in Table 1 and illustrated Fig 1 and 3.2 the highest availability of nitrogen (160.14 kg ha⁻¹), phosphorus (19.05), potassium (537.40 kg ha⁻¹), sulphur (12.77 kg ha⁻¹) was observed in the treatment T₆ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + humic acid @ 10 kg ha⁻¹, at harvesting, which was at par with treatment T₇ 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + humic acid @ 10 kg ha⁻¹ i.e. N (153.11 kg ha⁻¹), P (18.44 kg ha⁻¹), K (529.93 kg ha⁻¹). However, sulphur is at par with treatment T₄ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* S (12.52 kg ha⁻¹). The treatment T₁ 100% RDF had recorded as lowest available nitrogen (150.52 kg ha⁻¹), potassium (504 kg ha⁻¹) and sulphur (9.087 kg ha⁻¹) in soil but lowest value of phosphorus (16.26) in treatment T₃. Higher levels of available N, P, K, and S were observed in soil in treatment T₆, which included 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. This is because Sulphur, with the help of SOB, encourages nitrogen assimilation and phosphorus solubilisation, while *Rhizophos* increases phosphorus availability through microbial activity. Humic acid enhances root growth, nutrient retention, and soil structure, which helps rajma crops absorb NPKS more effectively.

Similar results were found by Dhanve *et al.* (2015)^[6] in assessment of soil fertility in the field of Badnapur.

3.4 Micronutrient status of soil

The statistics on the DTPA micronutrients (zinc and manganese) content of the soil at the time of harvesting stage are, presented in Table 2 and illustrated in Fig 2 the results revealed that the highest DTPA Zn (1.31 mg ha⁻¹) and Mn (5.25 mg ha⁻¹) was observed in treatment T₇ i.e. 100% RDF + 25 kg ZnSO₄ ha⁻¹ +

seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. Which was at par with treatments T₃ 100% RDF + 25 kg ZnSO₄ ha⁻¹ (1.23 mg ha⁻¹). but manganese was at par with treatment with T₆ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + humic acid @ 10 kg ha⁻¹. The lowest Zn and Mn content in the soil was found in treatment T₁ i.e. 100% RDF (0.53 mg ha⁻¹) and (3.79 mg/ha).

The statistics on the DTPA micronutrients Iron and copper content of the soil at the rajma harvesting stage are presented in Table 3 and illustrated in Fig.2. The revealed that the highest DTPA Fe (1.92 mg ha⁻¹) and Cu (1.76 mg ha⁻¹) content was observed in treatment T₆ i.e. 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. It was at par with treatments T₇ 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ i.e. Fe (1.89 mg ha⁻¹) and Cu (1.69 mg ha⁻¹). The lowest Fe (1.61 mg ha⁻¹) was found in treatment T₁ and Cu (1.39 mg ha⁻¹) content in the soil was found in treatment T₃.

Available Fe and Cu were observed in soil in treatment T₆, which included 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. And higher values of Zn and Mn were observed in the treatment 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹. Maruf *et al.* (2019)^[16] found similar results of availability DTPA micronutrients in soil by the application of sulphur and humic acid to soil. These results were in align with the results reported by Shaban *et al.* (2012)^[20] and Mackowiak *et al.* (2001)^[14] who indicated that application of humic acid positively influenced micronutrients availability, in soil and indicated that the availability of micronutrients.

The concentration of DTPA-extractable micronutrients—namely zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) is significantly enhanced when sulphur fertilization, humic acid, and biofertilizers are applied together. This improvement is primarily due to favorable changes in soil conditions that enhance the solubility and movement of these nutrients. The oxidation of sulphur by sulphur-oxidizing bacteria leads to a reduction in soil pH, which, in turn, increases micronutrient availability. Humic acid, rich in carboxylic and phenolic groups, functions as a natural chelate, reducing nutrient fixation and enhancing uptake by plants. Moreover, biofertilizers like *Rhizobium* and sulphur-oxidizing microbes stimulate microbial and enzymatic activity in the rhizosphere, further aiding in the transformation of micronutrients into forms that are readily accessible to plants.

Table 2: Effect of Sulphur fertilization, humic acid and biofertilizers application on availability of N, P, K and S in soil after harvest of Rajma

Treatments	Available Nutrients (kg ha ⁻¹)			
	N	P	K	S
T ₁ 100% RDF	150.52	16.53	504.00	9.08
T ₂ 100% RDF + 25 kg Sulphur ha ⁻¹	151.01	16.64	507.73	11.80
T ₃ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹	149.48	16.26	504.00	10.48
T ₄ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> .	153.11	17.89	515.20	12.52
T ₅ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> .	150.52	16.72	511.47	10.37
T ₆ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> + 10 kg humic acid ha ⁻¹ .	160.14	19.05	537.40	12.77
T ₇ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> + 10 kg humic acid ha ⁻¹ .	156.05	18.44	529.93	10.25
SE(m) ±	1.32	0.61	5.52	0.44
CD at 5%	4.06	1.89	17.00	1.37

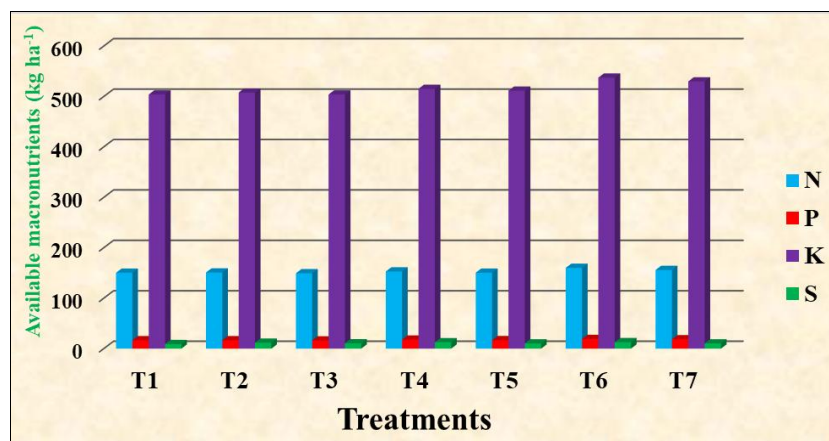


Fig 1: Effect Sulphur fertilization, humic acid and biofertilizers application on available macronutrients (N P K S) in soil after harvest of Rajma

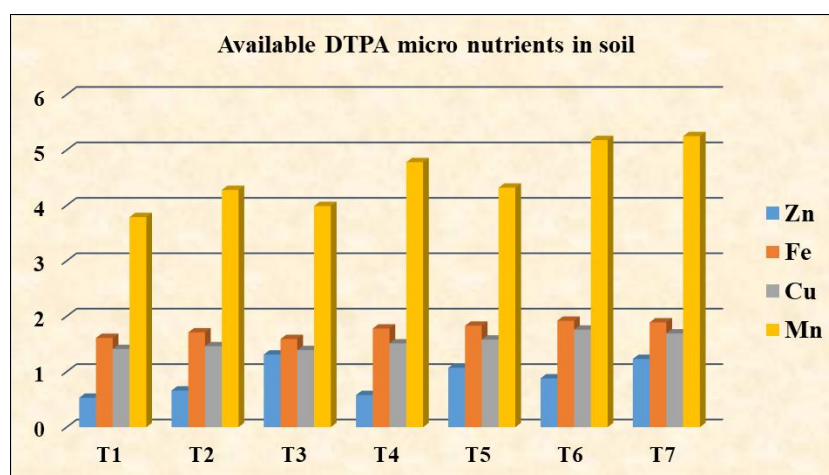


Fig 2: Effect Sulphur fertilization, humic acid and biofertilizers application on available DTPA micro nutrients in soil

Table 3: Effect of Sulphur fertilization, humic acid and biofertilizers application on availability of DTPA extractable micronutrients in soil after harvest of Rajma

Treatments	DTPA extractable micronutrients (mg ha ⁻¹)			
	Zn	Fe	Cu	Mn
T ₁ 100% RDF	0.53	1.61	1.41	3.79
T ₂ 100% RDF + 25 kg Sulphur ha ⁻¹	0.66	1.71	1.46	4.28
T ₃ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹	1.07	1.59	1.39	3.99
T ₄ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> .	0.58	1.78	1.51	4.78
T ₅ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> .	1.23	1.83	1.58	4.32
T ₆ 100% RDF + 25 kg Sulphur ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> + 10 kg humic acid ha ⁻¹ .	0.88	1.92	1.76	5.18
T ₇ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + seed inoculation of sulphur oxidizing bacteria + <i>Rhizophos</i> + 10 kg humic acid ha ⁻¹ .	1.31	1.89	1.69	5.25
S.E(m) ±	0.08	0.07	0.07	0.26
CD at 5%	0.26	0.22	0.23	0.80

3.5 Yield

3.5.1 Grain Yield

The effect of Sulphur fertilization, humic acid and biofertilizers application in rajma crop was noted and tabulated in Table 4 and Fig 3. The highest grain yield was recorded 1049 kg ha⁻¹ in treatment T₆ which involved 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ at harvesting which was found at par with treatment T₇ 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ (979 kg ha⁻¹) followed by treatment T₄ 100% RDF + 25 kg Sulphur ha⁻¹ + Sulphur oxidizing bacteria + *Rhizophos* (933.23 kg ha⁻¹). The treatment T₃ 100% RDF + 25 kg ZnSO₄ ha⁻¹ (780 kg ha⁻¹) was superior over the treatment T₁ 100% RDF which

had recorded lowest yield 625 kg ha⁻¹ among all the treatments.

Humic acid application to the soil improves nutrient and water absorption and promotes nutrient translocation, resulting in increased leaf, pod development, and reproductive part production, and eventually a higher grain yield.

The sulphur had significant influence on plant height, number of pods plant⁻¹ and length of dry pod, number of seeds pod⁻¹ grain yield (1.480 t ha⁻¹), stover yield (1.976 t ha⁻¹) with 10 kg S ha⁻¹ (S₁), biological yield and harvest index of French bean, the findings of similar trend in his trial On the other hand 20 kg S ha⁻¹ (S₃) grain yield (1.332 t ha⁻¹), biological yield (3.184 t ha⁻¹) Sahagufa *et al.* (2019) [19]. Increased grain and stover yield of pigeon pea with graded doses of S was due to more assimilation of sulphur in metabolic process of plant (Balpande *et al.* 2016)

[3]. Similar results found by Javed *et al.* (2024) [9]. significant enhancement in seed yield due to various humic acid application methods. The treatment with the statistically highest recorded seed yield (1487.70 kg ha⁻¹) involved the addition of humic acid at a rate of 4 kg ha⁻¹ to the soil (H₆). The significant increase in yield due to sulphur reflects its possible role in the synthesis of S-containing amino acids, proteins and enhanced photosynthetic activity of plant with increased chlorophyll synthesis (Juszczuk and Ostaszewska, 2011) [10].

3.5.2 Stover Yield

The effect of Sulphur fertilization, humic acid and biofertilizers application in rajma was noted and tabulated in Table 4 and Fig 3. Significant variations were observed in the stover yield of rajma with all the treatments due to the soil application Sulphur fertilization, humic acid and biofertilizers. The maximum Stover yield was recorded 1636. kg ha⁻¹ in the treatment T₆ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* + 10 kg humic acid ha⁻¹ in rajma at which was at par with 1527 kg ha⁻¹, in the treatment T₇ 100% RDF + 25 kg ZnSO₄ ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* +10 kg humic acid ha⁻¹ (1527 kg ha⁻¹), which was followed by treatment T₄ 100% RDF + 25 kg Sulphur ha⁻¹ + seed inoculation of sulphur oxidizing bacteria + *Rhizophos* (1456 kg ha⁻¹) and treatment T₂ 100% RDF + 25 kg Sulphur ha⁻¹ (1392 kg ha⁻¹). T₁ 100% RDF produced 974

kg ha⁻¹ straw yield and recorded least straw yield as compared to other. Application of Sulphur fertilization, humic acid and biofertilizers increases absorption of nutrients and water, translocation of nutrients ultimately produces high foliage, pods, reproductive parts cause high grain yield. Sulphur oxidizing bacteria might also have acted on native and applied sulphur and might have converted it to SO₄ making sulphur more available for proper growth and growth attributes related to increase in grain yield and straw yield. Similar results were found by Sukne *et al.* (2024) [21]. The impact of spacing's and varieties of rajma, the Phule Rajma produced significantly higher seed yield (1525 kg ha⁻¹) and stover yield (2349 kg ha⁻¹). Dandge *et al.* (2016) [5] also noted highest grain and straw yield (2065 kg ha⁻¹ and 2890 kg ha⁻¹) with the application of 100% RDF + 2.5 l ha⁻¹ humic acid. The results align with the research carried out by Mane *et al.* (2024) observed maximum grain yield (2190 kg ha⁻¹) in the treatment (T₅) RDF + ZnSO₄ @ 25 kg ha⁻¹ + humic acid 15 kg ha⁻¹. The study investigated by Manna *et al.* (2023) [15] the impact of humic acid and sulphur on the biological yield of Indian mustard under varying water regimes. Results showed a significant increase in grain yield and biological yield when humic acid and sulphur were applied together, compared to control groups, across different water conditions.

Table 4: Effect of Sulphur fertilization, humic acid and biofertilizers, application on grain and stover yield (kg ha⁻¹)

Treatments	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)
T ₁ 100% RDF (60: 80: 00 kg ha ⁻¹ N, P ₂ O ₅ , K ₂ O)	625	974
T ₂ 100% RDF + 25 kg Sulphur ha ⁻¹	893	1392
T ₃ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹	780	1206
T ₄ 100% RDF + 25 kg Sulphur ha ⁻¹ + Seed inoculation of Sulphur Oxidizing Bacteria + <i>Rhizophos</i> .	933	1456
T ₅ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + Seed inoculation of Sulphur Oxidizing Bacteria + <i>Rhizophos</i> .	830	1295
T ₆ 100% RDF + 25 kg Sulphur ha ⁻¹ + Seed inoculation of Sulphur Oxidizing Bacteria + <i>Rhizophos</i> + 10 kg Humic acid ha ⁻¹	1049	1636
T ₇ 100% RDF + 25 kg ZnSO ₄ ha ⁻¹ + Seed inoculation of Sulphur Oxidizing Bacteria + <i>Rhizophos</i> + 10 kg Humic acid ha ⁻¹	979	1527
SE(m) ±	38	60.59
CD at 5%	116	186.73

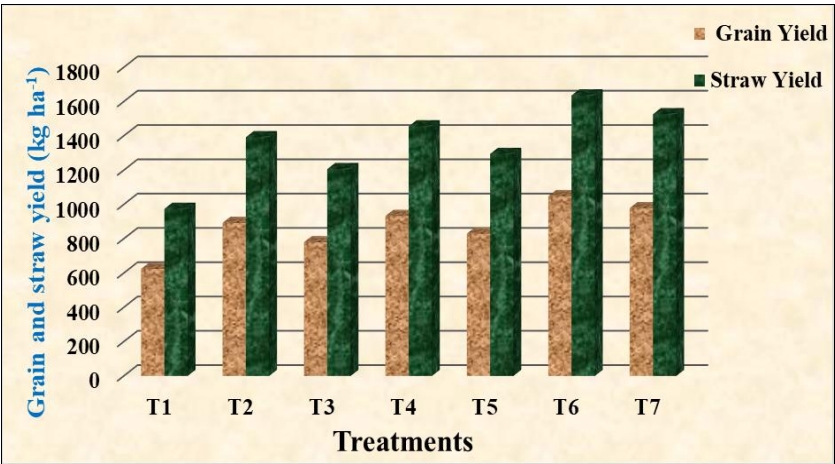


Fig 3: Effect Sulphur fertilization, humic acid and biofertilizers application on grain and stover yield

Conclusion

The field experiment's results clearly showed that the soil nutrient status in Rajma cultivation was greatly improved by the combined application of humic acid, sulphur fertilization, and biofertilizers. When compared to control and individual

treatments, treatments that included these elements boosted the soil's availability of macronutrients (N, P, K, S) and micronutrients (Zn, Fe, Mn, Cu). Better organic matter dynamics, increased microbial activity, and improved nutrient solubilisation are the causes of the synergistic benefits shown.

Grain and stover yield also increased by the combination of humic acid, elemental sulphur (at the ideal dosage), and dual inoculation with Rhizobium and sulphur-oxidizing bacteria was the most successful treatment in maintaining soil fertility. The significance of comprehensive nutrient management in fostering soil health and guaranteeing sustainable Rajma production is highlighted by these findings.

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