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Effect of Foliar Application of Thiourea on the Growth, Yield and Economics of Soybean (*Glycine max* L.)

Prema Sunkad[1], G. Somanagouda[2], R. Channakeshva[3], Roopa U.[4] and Nagesh Rathod[1]

[1]Dept. of Agronomy, College of Agriculture, Dharwad, University of Agricultural Sciences, Dharwad, Karnataka (580 005), India
[2]Dept. of Agronomy, [3]Dept. of Entomology, AICRP-Soybean, Main Agriculture Research Station, University of Agricultural Sciences, Dharwad, Karnataka (580 005), India
[4]Dept. of Food Science and Nutrition, MARS, University of Agricultural Sciences, Dhawad, Karnataka (580 005), India

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Corresponding Sgouda111@gmail.com

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ABSTRACT

A field experiment was conducted during *kharif* (June–October), 2020 at the MARS, UAS, Dharwad, Karnataka, India to study the influence of thiourea as foliar spray on soybean under the Northern Transition Zone of Karnataka under rainfed condition. The treatments were laid out in FRCBD with factorial concept with three replications. The treatments consisted of two factors, viz., soybean varieties and different thiourea levels with a single control. Sowing of different soybean varieties was not found significant on any of the parameters studied. Among different thiourea levels foliar application of thiourea at 750 ppm at 20–25 DAS and at 50–55 DAS recorded significantly higher plant height, number of branches plan^{-1}, leaf area index, total dry matter production, crop growth rate, relative growth rate, number of pods plant^{-1}, seed yield plot^{-1}, test weight, protein content, protein yield, nutrient uptakes (N, P and K), haulm yield (4192 kg ha^{-1}), seed yield (2582 kg ha^{-1}), gross return (₹ 94,551 ha^{-1}), net return (₹ 56,386 ha^{-1}) and benefit cost ratio (2.48) it was found on par with foliar application of thiourea at 500 ppm at 20–25 DAS and at 50–55 DAS and there was 44% increase in seed yield compared to control. Among the different interaction effect where thiourea has been sprayed at 750 ppm and 500 ppm on three different varieties at 20–25 DAS and at 50–55 DAS had recoded significantly higher productivity and economics returns of soybean.

KEYWORDS: Economics, nutrient uptake, soybean, thiourea, varieties, yield

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Soybean [*Glycine max* L. Merrill.] is an important oil seed and legume crop in the world. It provides (25%) of the global edible oil, about two-thirds of the world's protein source for livestock feed. Soybean meal is a valuable ingredient in feeds for poultry and fish (Meena et al., 2023). It contains about (40%) protein and (20%) oil, so it's known as a "wonder crop". India is fifth-largest producer of soybean in the world and has been adding area under soybean sowing since 2000 (Somanagouda et al., 2024). The crop also improves soil fertility status through symbiotic nitrogen fixation. Thus, it's miracle bean having many advantages and crop in fact made revolution in agriculture economy by Sahoo et al. (2023). Soybean is known to grow in different agro climatic conditions and its unmatched nutritional value, which make it one of the commercial crops in many countries including India. Soybean is major oil seed crop of world growing in an area of 140.00 mha and production of 394.96 mt with average productivity of 2820 kg ha^{-1} (Anonymous, 2023a). In the world it's cultivated mainly in USA, China, Brazil, Argentina and India. In India it's grown over an area of 13.00 m ha with production of 12.56 mt with productivity of 970 kg ha^{-1} (Anonymous, 2023b). The major soybean producing states in India are Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Karnataka and Gujarat. In Karnataka Soybean is cultivated in an area of 0.381 m ha with production of 0.437 m t and productivity of 1149 kg ha^{-1} (Anonymous, 2023). Belgaum, Dharwad, Bidar, Bagalkot and Haveri are the major soybean growing districts in Karnataka. Foliar application of agrochemicals is more beneficial than soil application and requires less quantity of agrochemicals through spraying. Undoubtedly, higher yield of soybean and quality of its oil is associated with foliar spraying of agrochemicals (Vahedi, 2011). Foliar spraying of agrochemicals is very helpful when the roots cannot provide necessary nutrients or unable to uptake of nutrients for plant (Kinaci and Gulmezoglu, 2007). Under limited soil moisture condition, it has been found that foliar application of agrochemicals is more influential as compared to soil application. It was suggested that agrochemicals could be applied successfully to compensate shortage of those elements and foliar spraying could be effective from 6 to 20 times as compared to soil application (Shoukat et al., 2022). Resistance to different stresses will be increased by foliar application of agrochemicals. Also effectiveness of foliar spraying is higher and the cost of foliar application is lower as compared to soil application (Yassen et al., 2010). Thiourea, also chemically named as Thiocarbamide, is a nitrogen and sulphur containing compound. It has three functional groups, amino, imino and thiol, each with important biological roles. Thiourea is being increasingly used to improve plant growth and productivity under normal and stressful conditions (Bola et al., 2024). Use of thiourea as seed priming agent, foliar spray or medium supplementation is more effective under environmental stress than under normal conditions. Thiourea is a sulphydryl compound (Jocelyn, 1972). In order to overcome the problems such as drought condition or less availability of soil moisture in semi-arid regions and for easy requirement of nutrients, spraying of different agrochemicals can be adopted to break the yield barriers of soybean crop. By keeping in view of the above advantages of foliar application of thiourea the present investigation entitled "Response of soybean to the foliar application of thiourea" was conducted with the following objectives. Productivity and economics returns of soybean as influenced by foliar application of thiourea.

2. MATERIALS AND METHODS

2.1. *Experimental site and growing conditions*

The field experiment was conducted during the *kharif*, June–October, 2020 at the Main Agricultural Research Station of the University of Agricultural Sciences in Dharwad, Karnataka, India, The geographical coordinates: latitude 15° 26' N, longitude 75° 07' E and at an altitude of 678 m above mean sea level. The research station came under Northern transition zone (Zone-8) of Karnataka which lied between the Western hilly zone (Zone 9) and Northern dry zone (Zone-3). The average rainfall was 1012.9 mm distributed in 70 rainy days. The total amount of rainfall received during cropping period was 828.2 mm (19th June to 20th Oct) distributed in 52 rainy days. The mean maximum temperature recorded during cropping period (4th Sept to 10th Sept) was 30.74 °C, lowest temperature during (28 Aug–3rd Sept) was 19.90 °C. The relative humidity was observed highest (93.86%) during 9th Oct to 15th Oct and lower relative humidity was observed in 4th Sept to 10th Sept (65.00%) (Figure 1). The soil was black clay (*Vertisol*) in texture with neutral in reaction, normal in electrical conductivity (0.32 dS m^{-1}), medium in organic carbon

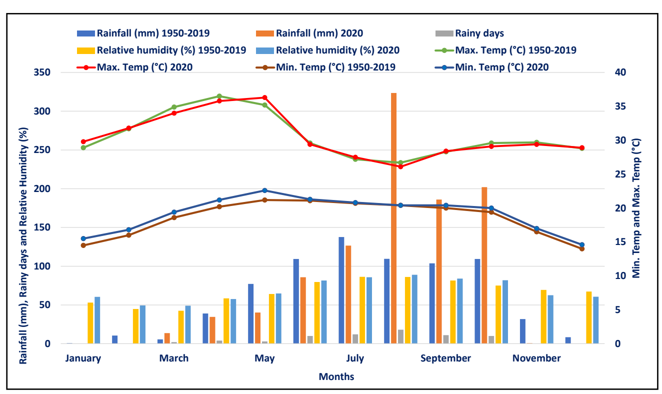

Figure 1: Monthly mean meteorological data during crop growth period (2020) and the average of past 69 years (1950-2019) at MARS, UAS, Dharwad

content (4.65 g kg^{-1}), low in available nitrogen (263 kg ha^{-1}), medium in phosphorus (30.5 kg ha^{-1}) and medium in potassium content (291 kg ha^{-1}).

2.2. Experimental design and layout

The experiment was laid out in factorial randomized complete block design with three replications comprising of 12 treatments and single control viz, T_1: JS 93–05 water spray, T_2: JS 93–05 thiourea at 250 ppm spray at 20–25 and 50–55 DAS, T_3: JS 93–05 thiourea at 500 ppm spray at 20–25 and 50–55 DAS, T_4: JS 93–05 thiourea at 750 ppm spray at 20–25 and 50–55 DAS, T_5: MACS 1188 water spray, T_6: MACS 1188 thiourea at 250 ppm spray at 20–25 and 50–55 DAS, T_7: MACS 1188 thiourea at 500 ppm spray at 20–25 and 50–55 DAS, T_8: MACS 1188 thiourea at 750 ppm spray at 20–25 and 50–55 DAS, T_9: DSb 21 water spray, T_{10} : DSb 21 thiourea at 250 ppm spray at 20–25 and 50–55 DAS, T_{11}: DSb 21 thiourea at 500 ppm spray at 20–25 and 50–55 DAS, T_{12} : DSb 21 thiourea at 750 ppm spray at 20–25 and 50–55 DAS, T_{13}: Control (RPP). The seeds of soybean variety JS 93–05, MACS1188 and DSb 21 at 80 kg ha^{-1} were used for sowing. At each spot two seeds were dibbled up to a depth of 2.5 to 3 cm in the seed line of 5 cm within the rows and 30 cm between the row spacing in the plots size of 3.6×6 m^2. After emergence of the crops, gaps in the field were filled by dibbling 2–3 seeds $hill^{-1}$. In order to maintain uniform plant population and reduced competition between seedlings by leaving one healthy seedling $hill^{-1}$, thinning was carried out by uprooting the extra and disease affected plants to maintain required plant population. Farm yard manure at recommended dose of 5 t ha^{-1} was applied uniformly and incorporated into the soil before 10 days of soybean sowing. Urea, di-ammonium phosphate (DAP) and muriate of potash (MOP) were used as sources of N, P_2O_5 and K_2O at recommended dose (40:80:25 kg NPK ha^{-1}) and applied entire dose as basal dose. Experimental land was kept free from weeds throughout the crop growth period. Hand weeding followed by inter cultivation were carried out 45 and 60 days after sowing, the intercultivation were carried out using cycle weeder and blade harrow. From each plot, five healthy plants were randomly selected to observe growth parameters. The observations on yield parameters were recorded at harvest. Harvesting was done manually excluding the two border rows on each side of a plot. Then the harvested crop was left as such in the field for two days for sun drying. The produce was then taken to the threshing floor and threshed separately for each plot manually. The haulm and seeds of each plot were dried separately in the sun. after proper cleaning and drying, seeds and haulm of each net plot were weighed and yields were recorded. The observations were recorded on plant height (cm), number of branches $plant^{-1}$, leaf area index, crop growth rate (g g^{-1} day^{-1}), relative growth rate (g m^{-2} day^{-1}) and yield parameters viz. number of pods $plant^{-1}$, seed yield $plant^{-1}$, test weight (g), seed yield (kg ha^{-1}), haulm yield (kg ha^{-1}), harvest index and qualitative traits, viz. protein content (%), protein yield (kg ha^{-1}) and nutrient uptake by plants (N, P and K). Nutrient uptake in seed and haulm was calculated by multiplying nutrient content by seed and haulm yield. Seed protein content (%): Nitrogen content in soybean seed was estimated by Kjeldhal method and Protein content in grains was calculated by multiplying the nitrogen content with a factor 6.25 (Tai and Young, 1974). Proline content (μg g^{-1}): In 1952, Chinard published that at acidic pH, ninhydrin could form a red product with proline and orinithone which could be used for the estimation of these amino acids in pure solution.

2.3. Statistical analysis

The experimental data obtained at different growth stages will be complied and subjected to statistical analysis by adopting Fischer's method of analysis of variance technique. The level of significance used in 'F' test will be at 0.05%. The treatment means were compared by Duncan's Multiple Range Test (DMRT) at 0.05 level of probability (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

3.1. Response of soybean to different varieties

Sowing of any other varieties was not found to be significant on any of the parameters studied.

3.2. Response of soybean to thiourea levels

3.2.1. Growth parameters of soybean

The application of thiourea spray at 750 ppm at 20–25 DAS and 50–55 DAS recorded higher growth parameters viz., plant height (64.16 and 66.82 cm), number of branches $plant^{-1}$ (5.85 and 6.78), total dry matter production (20.12 and 24.75 g $plant^{-1}$) at 60 DAS and at harvest time respectively, leaf area index (1.71 and 4.08), crop growth rate (26.08 and 36.51 g g^{-1} day^{-1}), relative growth rate (0.159 and 0.054 g m^{-2} day^{-1}) at 30 and 60 DAS, respectively which was found on par with thiourea application at 500 ppm at 20–25 DAS and at 50–55 DAS (Table 1). Thiourea enhances soybean growth by increasing the net photosynthetic rate, promoting photo-assimilation at sinks, accelerating cell division, and expanding leaf area, which boosts chlorophyll content and nutrient uptake (Ahmed et al., 2021). This results in improved plant height, branching, and more photosynthetically active leaves throughout vegetative and reproductive phases, enhancing energy absorption and overall growth. Abhishek et al. (2020) similarly reported that foliar application of thiourea at 1000 ppm improved plant growth, primary branches, and LAI in chickpea. The ridge sowing in association with mulch and foliar application of thiourea 1000 ppm mitigated moisture

Table 1: Growth parameters of soybean as influenced by different varieties and thiourea levels

Treatment details		Plant height (cm)		No. of branches plant^{-1}		TDMP (g plant^{-1})		LAI		CGR (g g^{-1} day^{-1})	
		60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest	30 DAS	60 DAS	30 DAS	60 DAS
Factor A: Soybean varieties											
A_1	JS 93–05	60.29^{a}	63.05^{a}	5.37^{a}	6.26^{a}	18.98^{a}	22.99^{a}	1.65^{a}	3.42^{a}	25.30^{a}	33.38^{a}
A_2	MACS 1188	61.11^{a}	63.32^{a}	5.44^{a}	6.31^{a}	18.99^{a}	22.99^{a}	1.63^{a}	3.42^{a}	24.48^{a}	33.47^{a}
A_3	DSb-21	62.18^{a}	64.42^{a}	5.46^{a}	6.36^{a}	19.29^{a}	23.32^{a}	1.63^{a}	3.44^{a}	24.58^{a}	33.43^{a}
SEm±	0.87	0.93	0.11	0.10	0.30	0.46	0.04	0.07	0.61	0.67	
Factor B: (TU) Thiourea levels (Spray at 20–25 and 50–55 DAS)											
B_1	Water spray	58.29^{b}	59.72^{b}	5.04^{b}	5.88^{b}	18.02^{b}	20.06^{c}	1.56^{a}	3.03^{b}	23.75^{a}	30.45^{bc}
B_2	TU spray at 250 ppm	59.71^{ab}	62.57^{ab}	5.16^{b}	6.09^{b}	18.73^{ab}	23.16^{b}	1.59^{a}	3.21^{b}	23.98^{a}	32.13^{b}
B_3	TU spray at 500 ppm	62.61^{a}	65.27^{a}	5.67^{a}	6.50^{a}	19.48^{a}	24.19^{a}	1.69^{a}	3.39^{ab}	25.33^{a}	34.62^{ab}
B_4	TU spray at 750 ppm	64.16^{a}	66.82^{a}	5.85^{a}	6.78^{a}	20.12^{a}	24.75^{a}	1.71^{a}	4.08^{a}	26.08^{a}	36.51^{a}
SEm±	1.00	1.07	0.13	0.12	0.35	0.54	0.05	0.22	0.71	0.78	
Interaction (A×B)											
T_1	A_1B_1	61.00^{ab}	59.67^{bc}	5.00^{c}	5.80^{c}	18.00^{bc}	21.39^{bc}	1.57^{a}	3.21^{bc}	24.00^{a}	30.46^{c}
T_2	A_1B_2	59.03^{bc}	62.08^{b}	5.20^{bc}	6.00^{bc}	19.00^{b}	23.29^{b}	1.58^{a}	3.28^{b}	25.29^{a}	32.09^{b}
T_3	A_1B_3	61.10^{ab}	64.31^{a}	5.60^{ab}	6.50^{a}	19.33^{ab}	23.83^{a}	1.73^{a}	3.48^{ab}	25.35^{a}	34.68^{ab}
T_4	A_1B_4	63.58^{a}	66.13^{a}	5.70^{a}	6.70^{a}	19.58^{a}	24.73^{a}	1.73^{a}	3.94^{a}	26.57^{a}	36.29^{a}
T_5	A_2B_1	58.22^{c}	60.83^{bc}	5.00^{c}	5.90^{bc}	18.04^{bc}	19.97^{c}	1.50^{a}	3.11^{bc}	23.46^{a}	30.23^{c}
T_6	A_2B_2	59.77^{bc}	62.00^{b}	5.20^{bc}	6.10^{ab}	18.70^{b}	23.32^{b}	1.57^{a}	3.15^{bc}	23.23^{a}	32.11^{b}
T_7	A_2B_3	62.01^{a}	64.76^{a}	5.80^{a}	6.50^{a}	19.30^{ab}	23.99^{a}	1.69^{a}	3.32^{ab}	25.18^{a}	34.72^{ab}
T_8	A_2B_4	64.43^{a}	65.67^{a}	5.90^{a}	6.80^{a}	19.93^{a}	24.68^{a}	1.75^{a}	4.09^{a}	26.44^{a}	36.44^{a}
T_9	A_3B_1	58.63^{c}	58.67^{bc}	5.00^{c}	5.90^{bc}	18.03^{bc}	20.13^{c}	1.60^{a}	2.99^{c}	23.79^{a}	30.65^{c}
T_{10}	A_3B_2	60.33^{bc}	63.62^{ab}	5.10^{bc}	6.10^{ab}	18.50^{b}	23.54^{ab}	1.62^{a}	3.21^{bc}	23.41^{a}	32.18^{b}
T_{11}	A_3B_3	64.71^{a}	66.73^{a}	5.70^{a}	6.60^{a}	19.80^{ab}	24.75^{a}	1.71^{a}	3.37^{ab}	25.47^{a}	34.45^{ab}
T_{12}	A_3B_4	65.03^{a}	68.67^{a}	6.00^{a}	6.90^{a}	20.83^{a}	24.84^{a}	1.60^{a}	4.21^{a}	25.23^{a}	36.81^{a}
Control		58.03^{c}	58.31^{c}	5.00^{c}	5.80^{c}	17.90^{c}	20.09^{c}	1.50^{a}	2.99^{c}	24.39^{a}	24.37^{d}
SEm±		1.68	1.88	0.24	0.24	0.58	0.96	0.09	0.14	1.27	1.40

Means followed by same letters in column or not statistically differed by DMRT (p=0.05)

stress in rainfed maize with amelioration across plant's defence through elaborated antioxidative defence system, compatible osmolyte accumulation, starch biosynthesis and their assimilation into developing sink organs for achieving the highest productivity levels (Singh et al., 2023).

3.2.2. Yield and yield parameters of soybean

Thiourea spray at 750 ppm at 20–25 DAS and at 50–55 DAS recorded higher number of pods plant^{-1} (46.50), seed yield plant^{-1} (30.75), test weight (15.04 g), seed yield (2582 kg ha^{-1}) haulm yield (4192 kg ha^{-1}) and lower harvest index (0.38). Which was closely followed by thiourea spray at 500 ppm at 20–25 DAS and at 50–55 DAS (Table 2). This improvement in seed yield might be attributed to enhanced crop photosynthesis, driven by increased photosynthetic efficiency and a stronger source-to-sink relationship, which together promoted growth-contributing traits. Thiourea spray significantly improved yield attributes, leading to higher seed yield. The sulfhydryl thiourea applications

Table 2: Growth, yield and yield parameters of soybean as influenced by different varieties and thiourea levels

Treatment details		RGR (g m^{-2} day^{-1})		No. of pods plant^{-1}	Seed yield plant^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index	Protein content (%)	Protein yield (kg ha^{-1})
		30 DAS	60 DAS								
Factor A: Soybean varieties											
A_1	JS 93–05	0.153^{a}	0.052^{a}	38.75^{a}	28.31^{a}	14.53^{a}	2386^{a}	3687^{a}	0.39^{a}	36.82^{a}	881.50^{a}
A_2	MACS 1188	0.153^{a}	0.052^{a}	40.46^{a}	28.42^{a}	14.54^{a}	2401^{a}	3702^{a}	0.39^{a}	36.89^{a}	888.40^{a}
A_3	DSb-21	0.151^{a}	0.053^{a}	41.63^{a}	28.52^{a}	14.68^{a}	2423^{a}	3721^{a}	0.39^{a}	36.71^{a}	893.38^{a}
SEm±	0.87	0.004	0.001	0.88	0.57	0.26	48.3	73.5	0.01	0.74	17.55
Factor B: (TU) Thiourea levels (Spray at 20–25 and 50–55 DAS)											
B_1	Water spray	0.152^{a}	0.032^{c}	33.16^{bc}	25.96^{b}	14.20^{a}	2157^{b}	3035^{c}	0.41^{a}	33.99^{c}	733.14^{c}
B_2	TU spray at 250 ppm	0.147^{a}	0.046^{b}	37.93^{b}	27.75^{ab}	14.44^{a}	2339^{ab}	3526^{b}	0.39^{a}	36.39^{b}	851.20^{b}
B_3	TU spray at 500 ppm	0.151^{a}	0.054^{ab}	43.53^{a}	29.20^{a}	14.67^{a}	2535^{a}	4061^{a}	0.38^{a}	37.37^{ab}	947.46^{ab}
B_4	TU spray at 750 ppm	0.159^{a}	0.076^{a}	46.50^{a}	30.75^{a}	15.04^{a}	2582^{a}	4192^{a}	0.38^{a}	39.48^{a}	1019.25^{a}
SEm±	1.00	0.005	0.001	1.01	0.66	0.30	55.8	84.9	0.01	0.86	20.26
Interaction (A×B)											
T_1	A_1B_1	0.150^{a}	0.032^{c}	31.44^{bc}	25.94^{b}	14.16^{a}	2146^{b}	3024^{c}	0.41^{a}	34.13^{bc}	732.43^{cd}
T_2	A_1B_2	0.143^{a}	0.046^{b}	35.64^{ab}	27.62^{ab}	14.43^{a}	2323^{ab}	3510^{b}	0.39^{a}	36.43^{abc}	846.27^{bc}
T_3	A_1B_3	0.159^{a}	0.053^{ab}	42.43^{a}	29.10^{a}	14.62^{a}	2502^{a}	4033^{a}	0.38^{a}	37.44^{ab}	936.75^{ab}
T_4	A_1B_4	0.160^{a}	0.075^{a}	45.48^{a}	30.59^{a}	14.92^{a}	2574^{a}	4182^{a}	0.38^{a}	39.26^{a}	1010.55^{a}
T_5	A_2B_1	0.156^{a}	0.031^{c}	33.26^{b}	25.95^{b}	14.11^{a}	2158^{b}	3036^{bc}	0.41^{a}	34.51^{bc}	744.73^{c}
T_6	A_2B_2	0.153^{a}	0.046^{b}	38.56^{ab}	27.78^{ab}	14.53^{a}	2328^{ab}	3514^{b}	0.39^{a}	36.42^{abc}	847.86^{bc}
T_7	A_2B_3	0.148^{a}	0.054^{ab}	43.32^{a}	29.18^{a}	14.59^{a}	2532^{a}	4063^{a}	0.38^{a}	37.23^{ab}	942.66^{ab}
T_8	A_2B_4	0.155^{a}	0.075^{a}	46.67^{a}	30.78^{a}	14.94^{a}	2584^{a}	4196^{a}	0.38^{a}	39.41^{a}	1018.35^{a}
T_9	A_3B_1	0.151^{a}	0.033^{c}	34.78^{b}	25.99^{b}	14.32^{a}	2167^{b}	3045^{bc}	0.41^{a}	33.33^{c}	722.26^{d}
T_{10}	A_3B_2	0.145^{a}	0.047^{b}	39.60^{ab}	27.86^{ab}	14.37^{a}	2367^{ab}	3553^{b}	0.39^{a}	36.31^{abc}	859.46^{b}
T_{11}	A_3B_3	0.145^{a}	0.054^{ab}	44.82^{a}	29.32^{a}	14.80^{a}	2572^{a}	4088^{a}	0.38^{a}	37.44^{ab}	962.96^{ab}
T_{12}	A_3B_4	0.161^{a}	0.076^{a}	47.33^{a}	30.89^{a}	15.25^{a}	2587^{a}	4199^{a}	0.38^{a}	39.77^{a}	1028.85^{a}
Control		0.151^{a}	0.019^{d}	35.37^{c}	23.62^{c}	14.57^{a}	1752^{c}	2292^{d}	0.43^{a}	32.12^{cd}	562.74^{e}
SEm±		0.009	0.002	1.74	1.21	0.51	100.4	149.9	0.02	1.59	34.23

Means followed by same letters in column or not statistically differed by DMRT (p=0.05)

improved the morpho-physiology, biochemical, and yield attributes of wheat varieties, thereby mitigating the adverse effects of drought (Ishfaq et al., 2024). The similar results were also reported by Bola et al. (2024) that is foliar application of boron 0.3%, urea 2.0% and MOP 0.5% at Ludhiana and MOP 0.5%, potassium nitrate 1.5% and urea 2.0% at Ballowal Saunkhri increased growth (plant height and dry matter accumulation), yield attributes (number of pods plant^{-1}, number of filled pods plant^{-1} and 100-seed weight) and seed yield.

3.2.3. Quality parameters of soybean

Thiourea spray at 750 ppm at 20–25 DAS and at 50–55 DAS recorded higher mean protein content and mean protein yield (39.48 %, 1019.25 kg ha^{-1}) respectively and it was on par with thiourea spray at 500 ppm at 20–25 DAS and at 50–55 DAS (Table 2). The increase in protein content might be due to higher nitrogen concentration in soybean grains, resulting from thiourea foliar spray, which promoted protein synthesis and contributed to higher seed yield (Kausar et al., 2023). Bola et al. (2024) reported that

Table 3: Proline content, nutrients uptake and economics of soybean as influenced by different varieties and thiourea levels

Treatment details		Proline content (µg g^{-1})	Nutrient uptakes (kg ha^{-1})			Cost of cultivation	Gross returns	Net returns	B-C ratio
			N	P	K	₹ ha^{-1}			
Factor A: Soybean varieties									
A_1	JS 93–05	233.25^{a}	81.62a	18.93a	59.44^{a}	37,823	87,206^{a}	49,383^{a}	2.30^{a}
A_2	MACS 1188	230.75^{a}	81.31a	19.25a	59.86^{a}	37,823	87,720^{a}	49,897^{a}	2.32^{a}
A_3	DSb-21	232.50^{a}	82.54a	19.13a	60.99^{a}	37,823	88,535^{a}	50,712^{a}	2.34^{a}
SEm±	0.87	4.74	1.64	0.37	1.23	-	17,63	1763	0.05
Factor B: (TU) Thiourea levels (Spray at 20–25 and 50–55 DAS)									
B_1	Water spray	224.00^{a}	74.33^{c}	16.24^{c}	55.41^{c}	37,481	78,530^{b}	41,049^{b}	2.10^{b}
B_2	TU spray at 250 ppm	229.00^{a}	78.83^{b}	18.10^{bc}	58.51^{bc}	37,705	85,402^{ab}	47,693^{ab}	2.26^{ab}
B_3	TU spray at 500 ppm	235.67^{a}	84.71^{ab}	20.12^{ab}	62.02^{ab}	37,937	92,798^{a}	54,861^{a}	2.45^{a}
B_4	TU spray at 750 ppm	240.00^{a}	89.43^{a}	21.94^{a}	64.45^{a}	38,165	94,551^{a}	56,386^{a}	2.48^{a}
SEm±	1.00	5.48	1.89	0.43	1.42	-	2036	2036	0.05
Interaction (A×B)									
T_1	A_1B_1	226.00^{a}	74.19^{d}	16.09^{cd}	55.24^{bc}	37,481	78,134^{b}	40,653^{b}	2.08^{b}
T_2	A_1B_2	230.00^{a}	79.35^{bc}	18.13^{bc}	58.36^{b}	37,789	84,815^{ab}	47,106^{ab}	2.25^{ab}
T_3	A_1B_3	237.00^{a}	84.78^{ab}	20.16^{b}	61.46^{ab}	37,937	91,603^{a}	53,666^{a}	2.41^{a}
T_4	A_1B_4	240.00^{a}	88.18^{ab}	21.32^{ab}	62.68^{a}	38,165	94,272^{a}	56,107^{a}	2.47^{a}
T_5	A_2B_1	222.00^{a}	74.39^{cd}	16.35^{cd}	55.24^{bc}	37,481	78,566^{b}	41,085^{b}	2.10^{b}
T_6	A_2B_2	228.00^{a}	78.79^{bc}	18.87^{bc}	58.77^{b}	37,789	84,994^{ab}	47,285^{ab}	2.25^{ab}
T_7	A_2B_3	234.00^{a}	83.61^{ab}	20.11^{b}	61.64^{ab}	37,937	92,683^{a}	54,746^{a}	2.44^{a}
T_8	A_2B_4	239.00^{a}	88.43^{ab}	21.66^{ab}	63.81^{a}	38,165	94,636^{a}	56,471^{a}	2.48^{a}
T_9	A_3B_1	224.00^{a}	74.41^{cd}	16.29^{cd}	55.75^{bc}	37,481	78,890^{b}	41,409^{b}	2.10^{b}
T_{10}	A_3B_2	229.00^{a}	78.34^{bc}	17.29^{c}	58.42^{b}	37,789	86,398^{ab}	48,689^{ab}	2.29^{ab}
T_{11}	A_3B_3	236.00^{a}	85.73^{ab}	20.08^{b}	62.95^{ab}	37,937	94,108^{a}	56,171^{a}	2.48^{a}
T_{12}	A_3B_4	241.00^{a}	91.69^{a}	22.84^{a}	66.85^{a}	38,165	94,744^{a}	56,579^{a}	2.48^{a}
Control		223.97^{a}	61.04^{e}	11.92^{e}	48.88^{c}	36,7553	63,612^{c}	26,859^{c}	1.73^{c}
SEm±		9.12	3.42	0.76	2.58	-	3662	3662	0.10

Means followed by same letters in column or not statistically differed by DMRT (p=0.05)

agrochemicals showed positive effects on the biochemical parameters with increased levels of proline and total phenol content as well as improvements in total soluble sugars, starch and protein content in soybean crop.

3.2.4. Nutrients uptake by soybean

Similarly, foliar spray of thiourea at 750 ppm at 20–25 DAS and at 50–55 DAS increased the nitrogen, phosphorus and potassium uptake by soybean (89.43, 21.90, 64.45 kg ha^{-1} respectively) (Table 3). Enhanced nutrient uptake was linked to increased grain and straw yields, along with higher nutrient concentration at the cellular level. Thiourea likely improved plant metabolism, root physiology (due to the SH-group), and nutrient absorption from the rhizosphere. It also promoted beneficial soil microbes that mobilized essential nutrients. Meena and Sharma (2010) reported that foliar application of thiourea at 1000 ppm in red gram crop recorded significantly higher nitrogen uptake and phosphorus uptake as compared to foliar application of TIBA at the rate of 50 ppm.

3.3. Interaction effect of varieties and thiourea levels on soybean

There were many factors which determined the potential yield of crop. Out of which variety and nutrient level played a major role. Good variety coupled with better supply of nutrients had become important for higher growth, development and productivity of soybean. Interaction effect of different varieties and thiourea levels showed significant effect. Application of thiourea at 750 ppm on three different varieties at 20–25 DAS and at 50–55 DAS has recorded significantly higher seed yield (DSb 21: T_{12}-2587 kg ha^{-1}, MACS 1188: T_8-2584 kg ha^{-1}, JS 93-05: T_4-2574 kg ha^{-1}) which was closely on par with thiourea application at 500 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{11}-2572 kg ha^{-1}, MACS 1188: T_7- 2532 kg ha^{-1}, JS 93-05: T_3-2502 kg ha^{-1}) and the application of thiourea at 750 ppm on three different varieties at 20–25 DAS and at 50–55 DAS has recorded significantly higher haulm yield (DSb 21: T_{12}-4199 kg ha^{-1}, MACS 1188: T_8-4196 kg ha^{-1}, JS 93-05: T_4-4182 kg ha^{-1}) which was closely on par with thiourea application at 500 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{11}-4088 kg ha^{-1}, MACS 1188: T_7-4063 kg ha^{-1}, JS 93–05: T_3-4033 kg ha^{-1}). The increased seed yield and haulm yield was due to improved yield attributes viz., number of pods plant^{-1} (DSb 21: T_{12}-47.33, MACS 1188: T_8-46.67, JS 93–05: T_4-45.48) and seed yield plant^{-1} (DSb 21: T_{12}-30.89 g plant^{-1}, MACS 1188: T_8-30.78 g plant^{-1}, JS 93–05: T_4-30.59 g plant^{-1}) (Table 2). Increase in yield and yield attributes was due to higher growth in term of plant height, number of branches plant^{-1}, dry matter production plant^{-1}, leaf area index, CGR, RGR (Table 1 and 2). The thiourea enhanced crop photosynthesis by improving photosynthetic efficiency and source-to-sink relationships, which positively influenced growth parameters and ultimately increased seed yield. Foliar application of thiourea at 750 ppm, applied at 20–25 DAS and 50–55 DAS across three soybean varieties, significantly increased seed and haulm yield. This improvement was likely due to enhanced nutrient absorption from the rhizosphere and increased microbial activity, which mobilized essential nutrients. Thiourea also promoted better plant growth and development, leading to higher pod numbers, greater seed weight plant^{-1}, and improved photosynthate translocation and accumulation (Somanagouda et al., 2024). Increased thiourea levels contributed to better nutrient uptake and reproductive development, resulting in higher yields. Meena et al. (2023) reported that thiourea brought a positive influence on the crop, and the maximum improvement was recorded by foliar spraying of 750 ppm thiourea, which was statistically at par with the foliar spray of thiourea at the concentration of 500 ppm. Application of sulphydryl compounds had significant effects on growth, photosynthetic traits, activities of anti-oxidant enzymes and yield of moth bean (Nathawat et al., 2021) (Table 4).

3.4. Economics

Among the different thiourea levels significantly higher gross return, net return and B:C ratio were obtained with thiourea spray at 750 ppm at 20–25 DAS and at 50–55 DAS (₹ 94551 ha^{-1}, ₹ 56386 ha^{-1}, 2.48 respectively) which was closely followed by Thiourea spray at 500 ppm at 20–25 DAS and at 50–55 DAS (₹ 92798 ha^{-1}, ₹ 54861 ha^{-1}, 2.45 respectively) (Table 3). The higher yield reflects in gross and net monetary returns. Interaction effect showed that significantly higher gross return were recorded with thiourea spray at 750 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{12}-₹ 94744 ha^{-1}, MACS 1188: T_8-₹ 94636 ha^{-1}, JS 93–05: T_4-₹ 94272 ha^{-1}) which was closely on par with thiourea spray at 500 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{11}-₹ 94108 ha^{-1}, MACS 1188: T_7-₹ 92683 ha^{-1}, JS 93–05: T_3-₹ 91603 ha^{-1}) and higher net return were recorded with thiourea spray at 750 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{12}-₹ 56579 ha^{-1}, MACS 1188: T8-₹ 56471 ha^{-1}, JS 93–05: T_4-₹ 56107 ha^{-1}) which was closely on par with thiourea spray at 500 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{11}-₹ 56171 ha^{-1}, MACS 1188: T_7-₹ 54746 ha^{-1}, JS 93-05: T_3-₹ 53666 ha^{-1}) similarly higher B:C ratio were recorded with thiourea spray at 750 ppm on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{12}-2.48, MACS 1188: T_8-2.48, JS 93–05: T_4-2.47) which was closely on par with thiourea spray at 500 ppm

Table 4: Correlation coefficient between yield and yield parameters of soybean as influenced by different varieties and thiourea levels

Parameters	Number of pods plant^{-1}	Seed yield plant^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
Number of pods plant^{-1}	1				
Seed yield plant^{-1}	0.904**	1			
Test weight (g)	0.906**	0.766**	1		
Seed yield (kg ha^{-1})	0.831**	0.971**	0.625**	1	
Haulm yield (kg ha^{-1})	0.878**	0.984**	0.691**	0.992**	1

**: Significant at p=0.05

on three different varieties at 20–25 DAS and at 50–55 DAS (DSb 21: T_{11}-2.48, MACS 1188: T_7-2.44, JS 93-05: T_3-2.41) (Table 3). The higher gross return and net return in these interactions were due to higher seed yield and haulm yield, whereas significantly lower gross return and net return were recorded with control (₹ 63612 ha^{-1} and ₹ 26859 ha^{-1}) due to lower productivity of crop. Meena B. S. and Sharma D.D (2012) reported that foliar application of thiourea at 1000 ppm in red gram crop recorded significantly higher net returns as compared to foliar application of TIBA at the rate of 50 ppm. Foliar spray of thiourea @ 500 ppm twice at 25 and 45 DAS proved most effective to get higher yield and net return from summer greengram (Devi et la., 2015).

4. CONCLUSION

Foliar application of thiourea at 500 ppm at 20–25 DAS and at 50–55 DAS with any variety of soybean proved most productive in terms of improved growth parameters, yield and yield parameters and as well as nutrient uptake of soybean in Northern Transition Zone of Karnataka, South, India.

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