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Enhancing Soybean Performance with Foliar Application of Thiourea: A Study on Yield, Quality and Economics

Deepak Kumar Meena[1*], Ajay Kumar[2], Amit Bhatnagar[3], R.K. Sharma[4], Akshay Kumar Yogi[1], K. Srikanth Reddy[1], Pragya Naithani[5] and Tejveer Singh[6]

[1]Ph.D. Scholar, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi -110 012, India.
[2]Assistant Professor, Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand- 263 145, India.
[3]Senior Research Officer, Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand- 263 145, India.
[4]Professor, Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand- 263 145, India.
[5]Ph.D. Scholar, Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand- 263 145, India.
[6]Ph.D. Scholar, Division of Biochemistry, ICAR-Indian Agricultural Research Institute, New Delhi -110 012, India.

(Corresponding author: Deepak Kumar Meena)*
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ABSTRACT: Soybean is the second most significant source of vegetable oil in India, comprising 23 percent of total vegetable oil production after mustard. Since India is importing a significant amount of vegetable oil, soybean is crucial in addressing the shortage of edible oil in the country. In *kharif* 2020, a field study was carried out at N. E. Borlaug CRC, GBPUAT, Pantnagar, Uttarakhand to investigate the impact of foliar application of thiourea on soybean crop. The study involved two types of soybean varieties, PS 1347 and SL 958, and various concentrations of foliar sprays of thiourea (250, 500, and 750 ppm) in addition to water spray and control. The experiment was conducted using a factorial randomized block design with four replications. The impact of the treatments administered was assessed based on their effects on yield, quality, and economic indicators. It was recorded that PS 1347 variety was superior than SL 958 in majority of characters and recorded around 10.08 per cent higher biological yield than SL 958. Amongst the concentration of thiourea, use of foliar spray of thiourea @ 750 ppm reported maximum seed index (10.75 g), seed yield per plant (10.39 g/plant), haulm yield (5096 kg/ha) biological yield (7311 kg/ha), protein yield (901 kg/ha), oil yield (434 kg/ha), gross return (Rs. 85955/ha) and net returns (Rs. 49875/ha), which were statistically at par with the results obtained by the foliar application of 500 ppm thiourea at the same interval. However, protein and oil content showed no significant difference due to variety and foliar spray. Challenges in the study were selection of the suitable varieties for research that can represent the wider area of cultivation and other challenge is that foliar spray of thiourea was only compared with water spray and control. There is need to compare these treatments with other commonly used treatments in soybean to assess their relative effectiveness.

Keywords: Cultivars, Economics, Foliar spray, Quality, Soybean, Thiourea, Yield.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is an important edible legume crop in India, and it is primarily grown for its oil and protein-rich seeds. With a 23% share in total vegetable oil production in India, it is the second most significant source of vegetable oil after mustard (National Food Security Mission, 2018). This oil is extensively utilized for cooking and industrial purposes. Soybean is also used for the preparation of vanaspati ghee, soy milk, soy flour, soy cake, biscuits, and soya chunks.

Soybean is a major global crop with Brazil having the largest cultivation area and the USA as the leading producer. In the cultivation of soybean, India stands at the fourth position globally in terms of acreage and at the fifth position in terms of production (United State of Department of Agriculture, 2020). In India, soybean is mainly cultivated in the central and western parts of the country. In 2020-21, soybean cultivation in India covered an area of 11.33 million hectares, producing 13.79 million tonnes of soybeans with an average productivity of approximately 1007 kg per hectare. The major soybean cultivating states in India include Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, and Telangana, with Madhya Pradesh having the largest area under cultivation (5.60 million hectares), Maharashtra leading in production (6.20 million tonnes), and Telangana leading in productivity (1503 kg per hectare) (Agricultural Statistics at a Glance, 2021). Soybean is believed to continuously play a key role in fighting the deficit of edible oil in the country (Damodaran and Hegde 2010).

However, the productivity of soybean in India is quite low, and it faces several constraints related to its physiology, management, and external stresses. Some of the notable reasons for the low productivity of soybean include sink limited nature, leaf fall, flower drop, poor availability of quality inputs, poor adoption of improved technology, soil moisture stress, high temperature stress, erratic rainfall, and biotic stresses like pests and diseases. Out of all the environmental stresses that soybean crop faces, it is believed that irregular rainfall is the main cause of yield reductions (Engels *et al.,* 2017). Drought stress causes a decrease in the soybean plant's leaf area index, chlorophyll content, and relative water content. Additionally, it results in an increase in the level of osmolytes in the plant (Dong *et al.,* 2019).

To address these constraints, several measures can be taken, such as ensuring the supply of good quality seeds, dealing with biotic stresses through resistant varieties of soybean like PS 1347 and SL 958, and improving abiotic stress and nutrient management through the use of bio-regulators like thiourea. Thiourea, an organosulfur compound, is a well-known bio-regulator for plants that can help mitigate abiotic stresses and improve the nutrient management system in soybean cultivation (Makadia, 2018).

Thiourea has been shown to enhance the plant's defense against fungal and bacterial diseases (Meena and Meena, 2017). It can activate various defense mechanisms such as lignification, production of phytoalexins, and strengthening of the cell wall, which ultimately reduces the severity of the disease.

Thiourea can help alleviate abiotic stress such as drought, salinity, and heavy metal toxicity (Srivastava *et al.,* 2017). It has been shown to improve plant growth and photosynthesis under stress conditions. Thiourea helps to reduce the accumulation of reactive oxygen species (ROS) and also increases the activity of antioxidant enzymes, which ultimately leads to improved plant tolerance to abiotic stress (Hassanein *et al.,* 2015).

However, it is important to note that the efficacy of thiourea as a foliar spray for stress alleviation may vary depending on the plant species, concentration, and application method. Additionally, excessive use of thiourea can have negative impacts on plant growth and development. Therefore, it is recommended to use thiourea in moderation and according to the specific recommendations for each plant species and stress condition.

MATERIALS AND METHODS

A. Experimental site

The experiment was conducted during the *kharif* season of 2020 in the D7 block of the Norman E. Borlaug Crop Research Centre at G.B. Pant University of Agriculture and Technology in Pantnagar, Uttarakhand. The experimental site is situated at an altitude of 243.84 meters above mean sea level, 29^o North latitude and 79.50^o East longitude, in the foothills of the *Shivalik* range. The soil of the experimental site belongs to the Mollisol classification.

The region experiences hot and humid summers and extremely cold winters, with an average annual rainfall of 1420 mm. The majority of the rainfall is received between the months of June and September. The data recorded during the crop season (25th June – 7th Nov. 2020) showed that the weekly average maximum temperature ranged from 28.5°C to 34.2°C, while the minimum temperature ranged from 12.3°C to 26.8°C. The total rainfall during this period was 746.9 mm. The maximum and minimum sunshine hours were found to be 9.1 hours and 2.5 hours, respectively, during the standard meteorological week of July. Maximum evaporation (6.4 mm) was observed during standard meteorological week No. 30. Relative humidity was measured at 7 am and 2 pm, and it was found to be between 83 per cent and 93 per cent during the morning hours and 37 per cent and 78 per cent during the afternoon hours.

The soil at the experimental site was nearly neutral with a pH value of 6.8. The soil sample analysis revealed that it contained 0.96 per cent organic carbon, and had available nutrients such as 233 kg/ha of nitrogen, 22.5 kg/ha of phosphorus, 140 kg/ha of potassium, and 20.5 kg/ha of sulphur.

B. Experimental details

The experiment involved two varieties of soybean and five different foliar sprays (control, water spray, and three concentrations of thiourea) which were arranged using a factorial randomized block design. The two varieties used were PS 1347 (V_1) and SL 958 (V_2), while the five foliar sprays were control (T_1), water spray (T_2), thiourea at 250 ppm (T_3), thiourea at 500 ppm (T_4), and thiourea at 750 ppm (T_5). Water or thiourea foliar spray was conducted at varying concentrations during 23 and 54 days after sowing.

The crop was sown on 25th June 2020 and treated with fungicide and *Rhizobium japonicum*. Pre-emergence herbicide Pendimethalin 30 EC and Imazethapyr 10 SL at 21 DAS were applied for weed control, followed by hand weeding. Chlorantraniliprole 18.5 SC was applied at 63 DAS for insect management. The crop was irrigated once on 8th October, harvested on 7th November, and dried under sun before threshing manually. Seeds were sun-dried to achieve 12 per cent moisture before storage.

C. Observation and Analysis

To evaluate the impact of thiourea, five marked plants in each plot were observed and the average data was analysed. Five representative plants were used to collect seeds, which were then weighed. The average weight was considered the seed yield per plant in that plot.

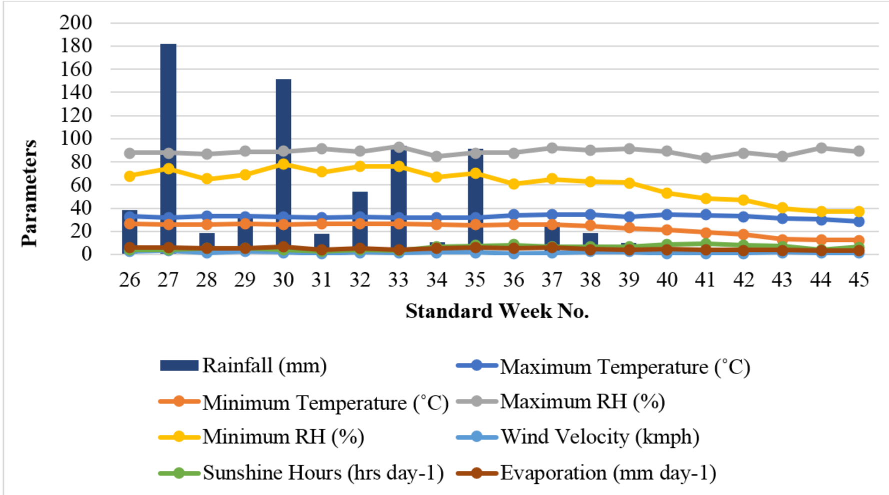

Fig. 1. Mean weekly meteorological parameters during crop growing season (*Kharif,* 2020).

After harvest, the crop was threshed, winnowed, and cleaned, and 100 seeds were weighed to determine the seed index of the soybean crop in each plot. The crop was harvested using a sickle, sun-dried for a few days, and weighed using a balance to determine the biomass yield. The recorded weights were converted to standard units of kg/ha through numerical conversions. The haulm yield was calculated indirectly by subtracting the seed yield from the total biomass yield of each plot.

To determine the protein content in the seed, the nitrogen content in the seed was multiplied by 5.71, following the suggestion of (Breese Jones, 1931).

$$\text{Seed protein content (\%)} = \text{N content in seed (\%)} \times 5.71$$

After harvest, seeds were dried, crushed to powder, and 2 grams of powder was weighed and put in a thimble. The thimble was taken to the Soxhlet chamber, where petroleum ether was used to extract oil from the sample for 6-7 hours at 80◦ . The oil content was obtained using the Soxhlet Extraction apparatus and petroleum ether as extractant (A.O.C.S., 1964).

The protein and oil yield were determined by multiplying the protein and oil content with the seed yield.

Economic analysis is an essential factor in evaluating the results and feasibility of any treatment. To determine economic feasibility, we need to calculate the cost of cultivating per unit area (□/ha), gross returns and net returns per unit area (□/ha). To calculate the gross return from the produce, we multiplied the approved minimum support price of soybean seeds set by the Government of India (Ministry of Agriculture and Farmers Welfare, 2020) with the amount of soybean seeds harvested. To determine the net returns, we subtracted the cost of cultivation for each treatment from their respective gross returns.

RESULT AND DISCUSSION

In order to investigate the impact of thiourea foliar spray on two distinct varieties of soybean, various parameters that relate to growth, yield, and quality of the produce were evaluated. A detailed explanation of the results obtained from these parameters is provided with scientific justification.

A. Seed Index

Seed index was calculated by weighing 100 seeds from each plot. PS 1347 had higher seed index (9.88 g) than SL 958 (9.08g). Thiourea foliar application at 750 ppm and 500 ppm showed significant increase in seed index compared to 250 ppm thiourea, water spray, and control. Thiourea at 250 ppm was superior to water spray and control, with a 12.08 per cent increase in seed index compared to control. The application of thiourea through foliar spray at 500 and 750 ppm rates led to a significant improvement in the seed index of soybean crop, with increases of 21.8 and 27.36 per cent respectively, when compared to the control. Better photosynthate assimilation and translocation to the economic part of the plant due to nitrogen and sulphur presence in thiourea improved the seed index. The results obtained were consistent with the findings of Jagetiya and Kaur (2006) and Abhishek *et al*. (2019) (Table 1, Fig. 2).

B. Seed yield/plant

Improvement in seed yield is the main objective in any agronomic experiment. And the factors involved in the experiment contributed to the yield of the soybean. PS 1347 recorded 15.92 per cent higher seed yield per plant (9.90 g/plant) as compared to the seed yield recorded by the variety SL 958 (8.54 g/plant). In case of foliar spray, the lowest seed production was recorded in control (8.02 g/plant) followed by water spray (8.11 g/plant). All the concentrations of thiourea used for foliar application proved to be superior over control and water spray. Application of thiourea at the rate of 250 ppm recorded the seed yield of 9.35 g/plant, which was 16.58 per cent higher than the control. Whereas the application of thiourea at the rate of 500 ppm showed an enhancement of 9.30 per cent in seed yield (10.22 g/plant) over the application of 250 ppm thiourea, which was statistically at par with the maximum seed yield (10.39 g/plant) obtained with the application of thiourea at the rate of 750 ppm.

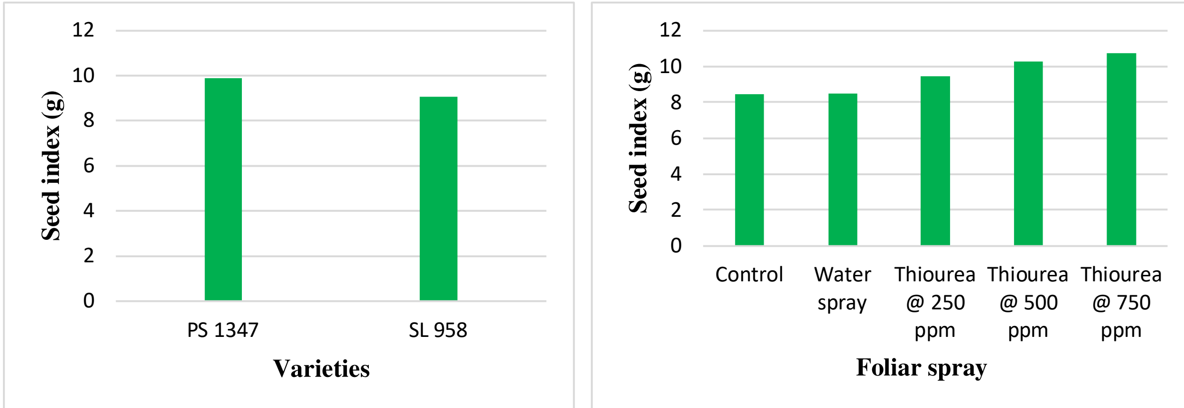

Fig. 2. Effect of varieties and foliar sprays on seed index of soybean crop.

Determinate nature of crop growth in PS 1347 variety of soybean led to the synchronus flowering and maturity of pods at the same time, which led to reduction in losses due to shattering of pods and resulted an ultimate increase in seed yield. The first and foremost reason would be the positive influence on photosynthetic activity by influencing the formation of chlorophyll and the activation and improved fuctioning of several chloroplastic enzymes under the influence of nitrogen and sulphur present in it Sulphur present in thiourea also protected the plants from several abiotic and oxidative stresses which led to better functioning of the plants under normal or stress conditions. Increase in number of braches per plant, number of pods per plant etc. ultimately led to the improvement in yield of the soybean crop. Research conducted by Anitha *et al*. (2004) and Bangar *et al.* (2019) also supported the findings of this experiment regarding seed yield (Table 1, Fig. 3).

C. Haulm Yield

During a field experiment, it was found that the yield of haulm was significantly affected by the two different soybean varieties, with PS 1347 producing 7.19 per cent more yield than SL 958. Statistical analysis showed that the highest haulm yield was obtained when thiourea was sprayed on the plants at a concentration of 750 ppm, resulting in an 11.14 per cent increase over the control. The yield was also significantly higher when thiourea was applied at 500 and 250 ppm, compared to the control and water spray. The interaction between the two soybean varieties and thiourea concentration did not have a significant effect on the yield. The difference in yield between the varieties was due to the difference in plant growth, with PS 1347 having higher plant height and dry weight per plant. The improvement in yield due to thiourea application was attributed to increased photosynthesis, which was a result of increased chlorophyll content and activity of chloroplast enzymes. The increase in haulm yield observed in this study was consistent with the results reported by Shankarappa *et al*. (2020) (Table 1, Fig. 4).

D. Biological Yield

The combination of seed yield and haulm yield is called biological yield, and this study found that using different soybean varieties and foliar sprays led to a significant increase in biological yield. The variety PS 1347 had a higher biological yield (7194 kg/ha) compared to SL 958 (6532 kg/ha), which was 9.16% lower. The control and water spray had the lowest biological yield, while foliar application of thiourea resulted in a better yield. The best results were seen with thiourea spray at a concentration of 750 ppm, which led to a 15.08% increase in biological yield (7311 kg/ha) compared to the control. The interaction between varieties and thiourea spray did not significantly affect the biological yield. The increase in biological yield was due to the improvement in dry weight per plant, seed yield, and haulm yield. These findings were supported by previous studies conducted by Bochalia *et al.* (2013) and Yadav *et al.* (2020) (Table 1, Fig. 5).

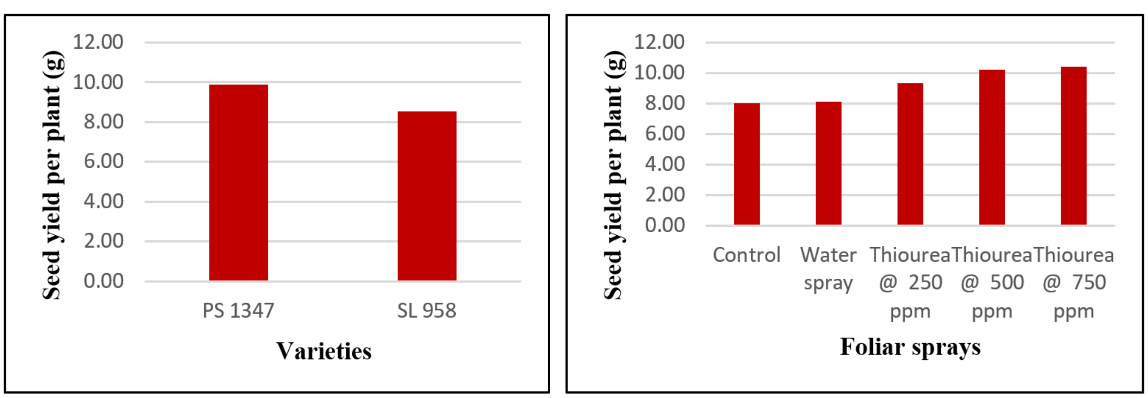

Fig. 3. Effect of varieties and foliar sprays on seed yield/plant of soybean crop.

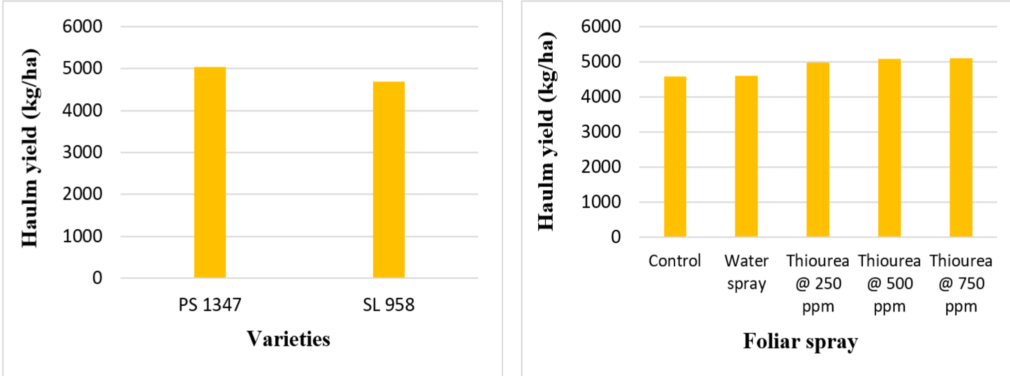

Fig. 4. Effect of varieties and foliar sprays on haulm yield of soybean crop.

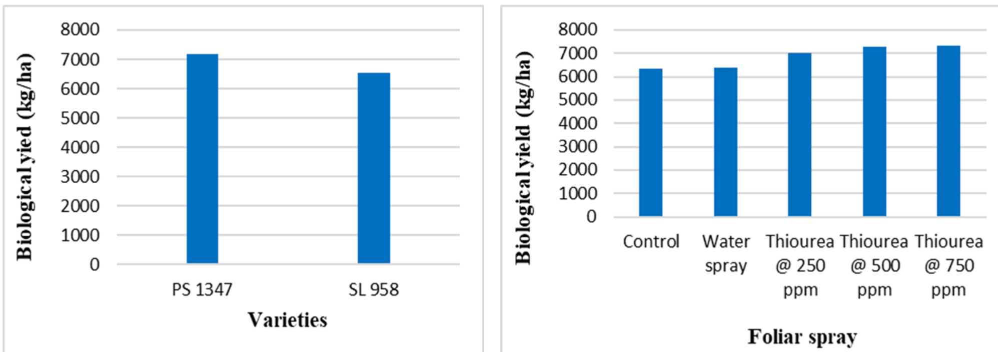

Fig. 5. Effect of varieties and foliar sprays on biological yield of soybean crop.

Table 1: Effect of different treatments on seed index, seed yield per plant, haulm yield and biological yield of soybean crop.

Treatments	Seed Index	Seed yield per plant	Haulm yield (kg/ha)	Biological yield (kg/ha)
Variety				
PS 1347	9.88	9.90	5036	7191
SL 958	9.08	8.54	4698	6532
SEm±	0.22	0.16	85	112
CD (*p*=0.05)	0.63	0.47	247	324
Foliar Spray				
Control	8.44	8.02	4585	6353
Water spray	8.47	8.11	4594	6364
Thiourea @ 250 ppm	9.46	9.35	4981	7010
Thiourea @ 500 ppm	10.28	10.22	5079	7267
Thiourea @ 750 ppm	10.75	10.39	5096	7311
SEm±	0.35	0.26	134	177
CD (*p*=0.05)	1.00	0.74	389	513

E. Protein content and yield

There was no significant difference in protein content in the seeds due to the variety and foliar spray, although a slight increase was observed with thiourea spray, but this increase was not statistically significant. Both the variety and foliar spray influenced the total protein yield from the crop. The PS 1347 variety had a 19.01 per cent higher protein yield compared to SL 958. The foliar spray had a significant effect on protein yield compared to the control. Thiourea application at a rate of 750 ppm resulted in 901 kg/ha of protein yield, which was statistically similar to the protein yield obtained with thiourea at rates of 250 and 500 ppm. The increase in total protein yield may be attributed to the increase in seed yield as the improvement in protein content in the seeds was not significant enough to have a notable impact on seed yield (Table 2, Fig. 6).

F. Oil content and yield

The quality of soybean crop is often evaluated based on the oil content it possesses. The foliar spray of thiourea did not show a significant difference in oil content compared to control, with a range of variation from 19.04 to 19.55 percent. The interaction between the varieties and foliar sprays in terms of oil content was also non-significant. However, the oil yield was influenced by the use of different varieties and foliar spray, with PS 1347 showing 19.03 percent more oil yield than SL 958. Among the different concentrations of thiourea, 500 and 750 ppm showed statistically similar results, with 750 ppm recording the highest oil yield of 434 kg/ha. The increase in oil yield can be attributed to the increase in seed yield of soybean, as the oil content did not show a significant difference (Table 2, Fig. 7).

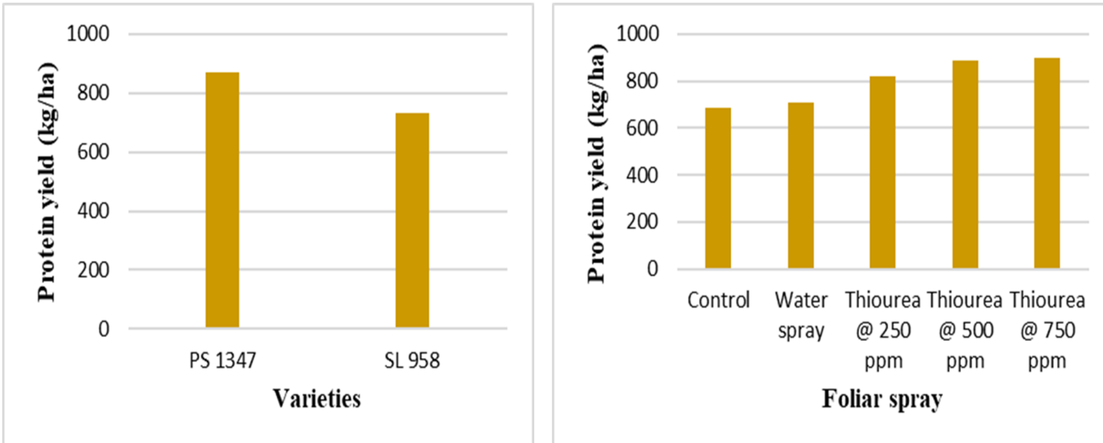

Fig. 6. Effect of varieties and foliar sprays on protein yield of soybean crop.

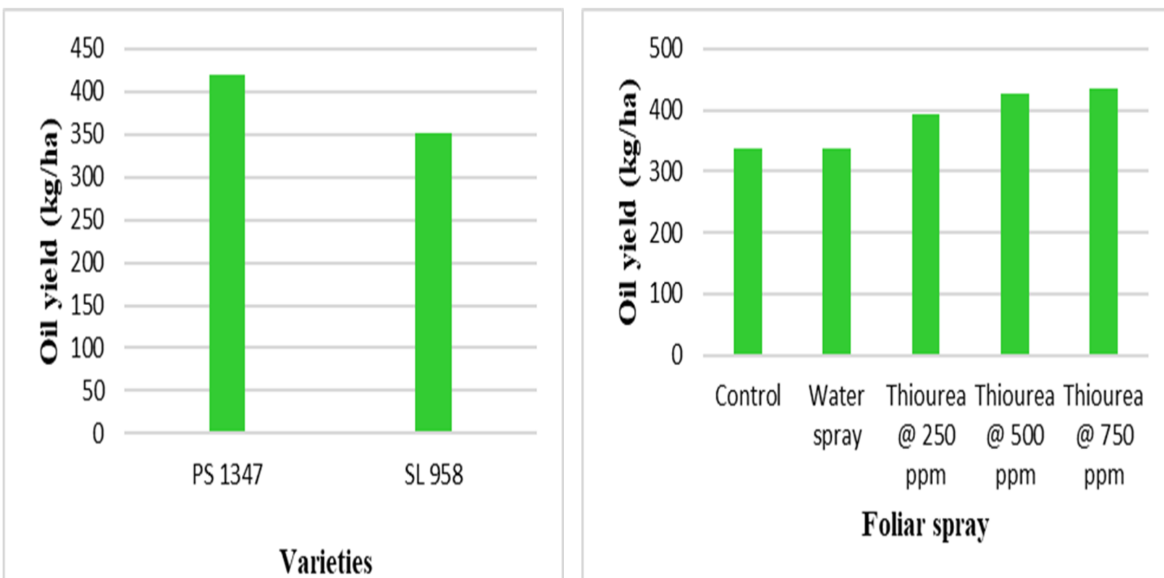

Fig. 7. Effect of varieties and foliar sprays on oil yield of soybean crop.

G. Gross returns

In a study comparing two rice varieties, PS 1347 had a 17.56 per cent higher gross return than SL 958. Applying thiourea through foliar spray resulted in the highest gross return at 750 ppm, which was equally effective as the application at 500 ppm. Both of these treatments showed better results than the control, water spray, and thiourea application at 250 ppm. Applying thiourea at 250, 500, and 750 ppm led to an increase in gross return by 14.96 per cent, 23.72 per cent, and 25.33 per cent, respectively, compared to the control. However, there was no evident interactive effect between the factors. The increase in gross return was directly related to the increase in seed yield, and there was not much difference in cultivation costs. This finding is consistent with a similar study by Bangar *et al.* (2019) that also reported an improvement in gross return (Table 3, Fig. 8).

H. Net Returns

The study showed that PS 1347 had better net returns than SL 958. The lowest net returns were seen in control and water spray, which were statistically similar to each other. Thiourea foliar spray, at all concentrations, improved net returns. Applying thiourea at 250 ppm resulted in a 24.54 per cent increase in net returns, while applying it at 750 ppm resulted in the maximum net return, which was similar to the net return from 500 ppm.

Table 2: Effect of different treatments on protein and oil content and yield in seeds of soybean crop.

Treatments	Protein content (%)	Protein yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
Variety				
PS 1347	40.37	869	19.42	419
SL 958	39.80	731	19.18	352
SEm±	0.69	18	0.08	7
CD (p = 0.05)	NS	51	NS	20
Spray				
Control	38.53	685	19.04	337
Water spray	39.95	707	19.12	338
Thiourea @ 250 ppm	40.51	821	19.34	392
Thiourea @ 500 ppm	40.57	888	19.45	426
Thiourea @ 750 ppm	40.84	901	19.55	434
SEm±	1.09	28	0.13	11
CD (p = 0.05)	NS	81	NS	32

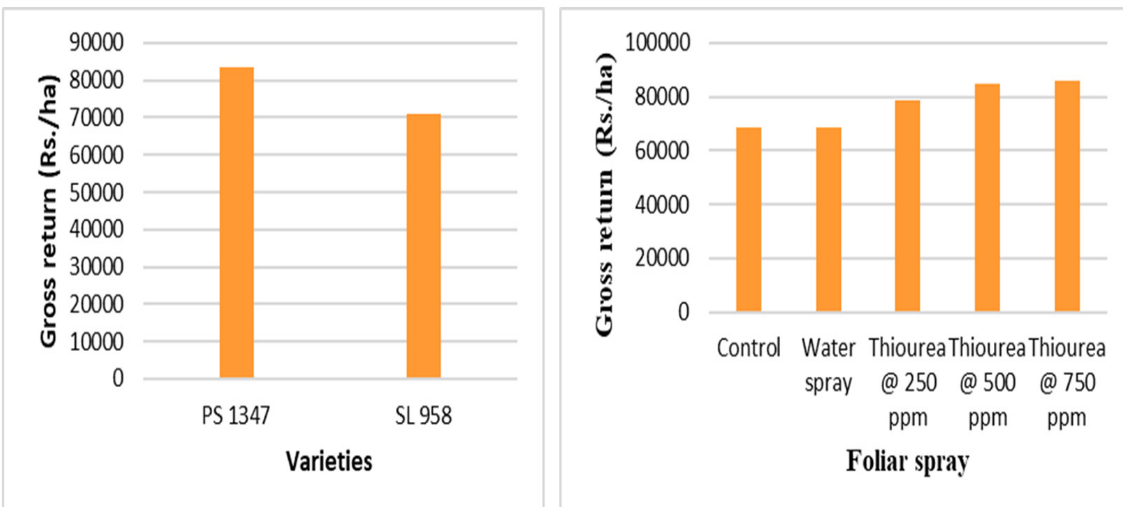

Fig. 8. Effect of varieties and foliar sprays on gross returns of soybean crop.

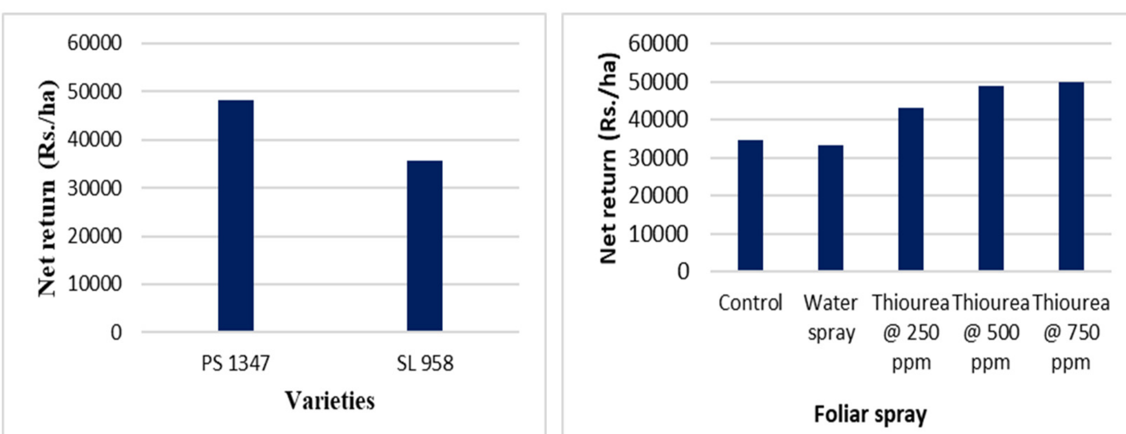

Fig. 9. Effect of varieties and foliar sprays on net returns of soybean crop.

Table 3: Effect of different treatments on economics of soybean crop.

Treatments	Cost of cultivation	Gross return	Net return
Variety			
PS 1347	35466	83590	48124
SL 958	35466	71140	35675
SEm±	-	1304	1304
CD(p=0.05)	-	3785	3785
Foliar Spray			
Control	33988	68585	34597
Water spray	35588	68685	33097
Thiourea @ 250 ppm	35756	78742	42986
Thiourea @ 500 ppm	35916	84858	48941
Thiourea @ 750 ppm	36080	85955	49875
SEm±	-	2062	2062
CD(p=0.05)	-	5984	5984

This improvement was due to the higher seed yield potential of PS 1347 and yield improvement from foliar thiourea application, which increased the cost of cultivation slightly but led to an overall increase in gross return. Previous studies by Choudhary *et al.* (2017) and Premaradhya *et al.* (2018) also found that thiourea application improved net returns (Table 3, Fig. 9).

CONCLUSIONS

After conducting a year-long study, it was determined that PS 1347 variety of soybean produced better seed index, yield, protein yield, oil yield, and economic returns compared to SL 958 variety. Thiourea spray at 500 ppm and 750 ppm showed the most consistent and significant response among the foliar applications tested. Both were statistically at par with each other. There was no significant interaction observed between the two factors. Therefore, it can be inferred that using PS 1347 variety of soybean and applying thiourea at 500 ppm during the 23 and 54 DAS is a commendatory option and most remunerative for farmers to improve the productivity and profitability of soybean in India.

FUTURE SCOPE

This research puts way forward for various researches and analysis related to the appropriate use of foliar spray of thiourea on soybean. Following can be the few areas of interest:

- To find out if continuous application of thiourea results any improvement in oil and protein content of soybean.
- To assess the presence (if any) of correlation between several effects of thiourea.
- To find out a beneficial and economical recommendation of foliar spray on all varieties of soybean.

Author contributions. This work was carried out in collaboration with all authors. Deepak Kumar Meena, Dr. Ajay Kumar, Dr. Amit Bhatnagar, and Dr. R.K. Sharma designed the study, performed the statistical analysis, wrote the protocol, and created the initial draft of the manuscript that guided the study analyses. Deepak Kumar Meena collected the data from the field and carried out the lab analysis. Furthermore, Akshay Kumar Yogi, Pragya Naithani, and Tejveer Singh read and approved the final manuscript.

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Conflict of Interest: None.

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