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Jeevan HR
M.Sc. Scholar, Department of Agronomy, KSNUAHS, Shivamogga, Karnataka, India

C Sunil
Assistant Professor and Coordinator, Department of Agronomy, Organic Farming Research Centre, KSNUAHS, Shivamogga, Karnataka, India

Praveen V Kadam
Research Associate, Department of Agronomy, KSN UAHS, Shivamogga, Karnataka, India

Girijesh GK
Professor and Head, Department of Agronomy, KSN UAHS, Shivamogga, Karnataka, India

Santosh Onte
Scientist-B, Department of Agronomy, Land and Water management Research group, KSCSTE-CWRDM, Kozhikode, Kerala, India

Mallikarjuna HB
Assistant Professor, Department of Statistics, KSNUAHS, Shivamogga, Karnataka, India

Sarvajna B Salimath
Associate Professor, Department of Soil Science and Agriculture Chemistry, KSNUAHS, Shivamogga, Karnataka, India

Chandan BM
M.Sc. Scholar, Department of Agronomy, KSNUAHS, Shivamogga, Karnataka, India

Corresponding Author:
C Sunil
Assistant Professor and Coordinator, Department of Agronomy, Organic Farming Research Centre, KSNUAHS, Shivamogga, Karnataka, India

Influence of varied levels and methods of molybdenum application on growth and yield in soybean (*Glycine max* L.)

Jeevan HR, C Sunil, Praveen V Kadam, Girijesh GK, Santosh Onte, Mallikarjuna HB, Sarvajna B Salimath and Chandan BM

Abstract
A field trial was carried out at AHRS Bavikere research Station, KSN University of Agricultural and Horticultural Sciences, Shivamogga, India, during *Kharif* 2021, to evaluate the effect of varied levels and methods of molybdenum (Mo) application in soybean**.** The experiment was laid out in Randomised Block Design with three replication. the trial comprised of various combinations of methods and levels (2, 4 and 6 g of Mo per kg of seed for seed treatment, 500,700,1000 and 1500 g/ha Mo as basal soil application and 0.025, 0.05 & 0.1% foliar Mo applications). The results revealed,significantly higher plant height (58.6 cm) number of branches per plant (7.5) leaf area Index (1.7) and plants dry weight (26.7 g plant^{-1}) at harvest were recorded in seed treatment with 6 g Mo kg^{-1} of seeds (T_3) followed by soil application of 1000 g/ha of Mo (T8). The yield traits of soybean *viz*., pods plant^{-1} (56.9), No of grains pod^{-1} (3.5), Test weight (14.2 g) seed yield per plant (13.6 g) were higher in seed treatment (6 g/ha) and soil application (1000 g/ha). Soybean root nodules observed at 35 and 45 DAS (44.2 and 63.5 per plant) were also significantly higher, in seed treatment with 6 g Mo kg^{-1} of seeds (T_3). Significant improvement in seed and haulm yield (1695.02 and 2520.0 kg ha^{-1}) was recorded, which was 17.3 and 12.7% higher in T_3 over control.

Keywords: Soybean, seed treatment, foliar spray, soil application, growth & yield

Introduction
Soybean (*Glycine max* L.) is a leguminous crop belongs to leguminoceae family and originated in China. The soybean has established itself as a rich source of protein (40-42%) and oil (20%) in addition to its high nutritional value has numerous uses in agriculture through improving soil fertility by fixing atmospheric nitrogen (50-300 kg ha^{-1}) and also adds 1.0-1.5 tons of leaf litter per season. Soybean is a major source of oil and protein in India as well as in the world as a human (oil) and poultry (protein feed). India is the highest importer of vegetable oil in the world (https://agricoop.gov.in). Monotonous cereal cultivation in India combined with excess application of nitrogenous fertilizers has caused the decline in productivity of soybean and nitrogen. Similarly faulty nitrogen management affected the environment causing the significant yield loss.

Apart from these factors affecting the sustained yield loss, major constraint for lower productivity of soybean is unbalanced nutrition. Soybean is provided with required nutrient input to produce sufficient biomass it does not exhibit its true potential for higher yields. Molybdenum is one of the essential plant nutrients required for plant growth and development. Although molybdenum is a micro nutrient in the plant metabolism, has a crucial role in nodule formation. Being an essential component of the enzyme nitrate reductase, it helps in conversion of NO^{3-} to NO^{2-}, which is important for nitrogen fixation, nitrate reduction and N transport in plants; it is also structural component of enzyme nitrogenase which is actively involved in atmospheric N_2 fixation by root nodule bacteria of leguminous crops (Ref….). The quality parameters like protein synthesis and Sulphur metabolism are also influenced by molybdenum (Santos *et al.*, 2000) [10]. Thus, multi-nutritional deficiency in the soil by faulty and imbalanced application of nutrients has affected the quality and quantity of yield of soybean. Therefore, in the recent year's micronutrients are considered as one of the constraints in production of crops.

Since the soils of this region are deficient in molybdenum element which have direct role in plant metabolism especially in leguminous crops and these aspects on soybean cultivation have received a very little attention particularly in soils of this locality.

Materials and Methods

Description of the site and treatment setup

A field experiment was carried out during the *Kharif* seasons of 2020-21 at Agricultural and Horticultural Research Station, Bavikere, KSNUAHS, Shivamogga, situated at longitude latitude of 75°51`E, 13°42`N & 695m above the mean sea level. The investigation site had red sandy loam in texture, slightly acidic and non-saline (pH 5.71, EC: 0.24 dSm^{-1}), low in organic carbon (0.56%) (Walkly and Black. 1934) [13], low in available nitrogen (215.64 kg ha^{-1}) (Subbiah and Asija. 1956) [12], high in available phosphorus (24.60 kg ha^{-1}) (Jackson 1973) [16] and high in available potassium (241.32 kg K_2O ha^{-1}) (Jackson 1973) [16]. The DTPA extractable molybdenum was 1.01mg kg^{-1} (Lindsay and Norwell. 1978) [15]. The experimental site falls under the Southern Transition Zone - warm humid of Karnataka. The mean temperatures during the experiment were 30-36 °C in the day time and 21-15 °C at night. The relative humidity was 40 - 60% and plants were subjected to natural irradiance. Rainfall was well distributed during crop growing seasons; total rainfall received during the study period was 418.5 mm. The experiment was conducted in a randomized block design, replicated thrice consisting of 10 treatment combinations, *viz*., seed treatment with 2 g molybdenum (Mo) kg^{-1} of seeds (T_1), seed treatment with 4 g Mo kg^{-1} of seed (T_2), seed treatment with 6 g Mo kg^{-1} of seeds (T_3), 0.025% Mo foliar spray at 20 DAS (T_4), 0.05% Mo foliar at 20 DAS (T_5), 0.1% Mo foliar spray at 20 DAS (T_6), 500 g Mo soil application ha^{-1} (T_7), 1000g Mo soil application ha^{-1} (T_8), 1500g Mo soil application ha^{-1} (T_9), control (No Mo application) (T_{10}). A common package of practices (PoP) fallowed for all the treatments. The soybean (*Glycine max* L.). *JS-335* variety was sown in field at a spacing of 30 × 10 cm. Crop-based recommended dose fertilizer (RDF) for soybean was (N: P_2O_5:K_2O) were applied @ 25:60.50:25 kg ha^{-1}, respectively. For T_1, T_2, T_3 treatments are seed treated with 2,4, and 6 g molybdenum respectively. T_4, T_5, T_6 are applied with foliar application 0.025%, 0.050% and 0.1% molybdenum respectively. And T_7, T_8, T_9 applied with 500, 1000, 1500g molybdenum per ha^{-1}. Molybdenum was applied in the form of Ammonium molybdate having 52% of molybdenum. In foliar application treatments Mo was applied at 20 DAS. Plant protection chemicals, irrigation and weed management were taken accordance with a standard package of practices.

Data collection and statistical analysis

Observations were recorded on various phenological growth stages *viz*., plant height (cm), number of trifoliate leaves, leaf area, leaf area index, number of branches $plant^{-1}$, and number of effective and total number of root nodules. Destructive samples were collected for dry matter estimation (dried in a hot air oven at 60 °C) from the gross plot area. Leaves from five representative plants were fed to leaf area meter (Model LI-COR 3100) and leaf area index was calculated by dividing total leaf area by total ground area. The soybean is harvested with a sickle treatment wise separately, the yield from net plot area as converted into (kg ha^{-1}) and considered as final yield.

Statistical analysis

Data were statistically analysed using the analysis of variance (ANOVA) technique applicable to the randomized block design. The significance of the treatment effect was determined using F-test; the means of the treatments are tested using the critical differences (CD) at the 5% probability level.

Results

Growth and growth attributes of soybean

The results obtained in experiment varied significantly (p=0.05) with the treatments tested, highest plant height at 30, 60 90 and harvest DAS was noted in T_3 i.e., seed treatment with 6 g Mo (25.0, 55.2, 57.7 and 58.7cm) that was statistically on par with T_8 (22.4, 53.7, 56.2 and 57.2cm), respectively (Table 1). The control treatment (T_{10}, no Mo application) produced shorter plants at all stages (20.2, 37.7, 43.7 and 44.4) (T_{10}). Plant height as the dominant growth attribute linearly influences other attributes of the crop, thus accommodating higher branches. Significantly, higher number of branches were found in seed treatment with Mo @ 6 g kg^{-1} of seed (T_3) (4.02) and lowest in POP alone (T_{10}) (2.6). Similar observations were recorded at 60 and 90 DAS Seed treatment with Mo @ 6 g kg^{-1} of seed (T_3) (7.07, 7.20, and 7.53), respectively. Seed treatment was was on par with POP + soil application of Mo @ 1000 g ha^{-1} (6.87, 6.93 and 7.27). Similarly, at 60 and 90 DAS significantly higher number of trifoliate leaves and LAI was registered in the hierarchy seed treatment <soil application and foliar application @ 6 g kg^{-1} of seed (T_3), 1000g ha^{-1} (T_8) and 0.1% (T_6) at 30, 60, 90 DAS and at harvest, respectively, and least was found in control. The LAI reached maximum at 60 DAS and declined at the maturity (90 DAS). The highest LAI in our experiment was 2.03 at 60 DAS in T_3 (seed treatment with Mo @ 6 g kg^{-1} of seed) (2.0, 1.7 and 1.2) followed by T_8 (1.9, 1.7 and 1.2) at 60, 90 and at harvest, respectively.

Table 1: Plant height, number of branches and number of trifoliate leaves of soybean as influenced by different method and level of molybdenum application.

Treatments	Plant height (cm)				Number of branches $plant^{-1}$				Number of trifoliate leaves $plant^{-1}$	
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest	60 DAS	90 DAS
T_1 - Seed treatment with Mo @ 2 g kg^{-1} of seeds	20.97	47.26	50.34	51.18	3.15	5.40	5.53	5.87	9.13	7.23
T_2 - Seed treatment with Mo @ 4 g kg^{-1} of seeds	21.60	50.30	54.20	55.11	3.59	6.33	6.70	6.90	10.20	8.29
T_3 - Seed treatment with Mo @ 6 g kg^{-1} of seeds	25.00	55.23	57.67	58.65	4.02	7.07	7.20	7.53	11.80	9.89
T_4 - Foliar application of Mo at 0.025%	20.40	43.24	47.66	48.45	2.93	4.77	4.92	5.25	8.33	6.43
T_5 - Foliar application of Mo at 0.05%	20.87	46.23	49.63	50.46	3.07	5.13	5.37	5.71	8.73	6.86
T_6 - Foliar application of Mo at 0.1%	21.20	47.93	50.91	51.76	3.28	5.73	5.83	6.16	9.20	7.29
T_7 - Soil application of Mo @ 500 g ha^{-1}	21.47	48.36	51.52	52.39	3.33	5.93	6.27	6.60	9.46	7.56
T_8 - Soil application of Mo @1000 g ha^{-1}	22.40	53.67	56.19	57.15	3.91	6.87	6.93	7.27	10.26	8.36
T_9 - Soil application of Mo @1500 g ha^{-1}	21.60	49.51	53.73	54.63	3.48	6.13	6.67	6.87	9.73	7.66
T_{10} - Control (No Mo application)	20.20	37.66	43.68	44.39	2.66	4.27	4.63	5.43	7.60	5.69
S. Em.±	0.92	0.86	0.62	0.63	0.23	0.24	0.21	0.22	0.57	0.64
CD 5%	NS	2.56	1.86	1.89	NS	0.74	0.64	0.68	1.7	1.92

Dry matter accumulation (DMA) at various growth stages significantly varied due to different method and levels of molybdenum application (Table 2). The DMA increased with advancing the age of the crop, the rapid accumulation was noted during flowering stage to late grain filling. At 60 and 90 DAS 46.2 and 32.5% of DMA was recorded at 60 to 90 DAS. Application of Mo as seed treatment @ 6 g kg^{-1} of seed (T_3) accumulated higher dry matter (T_3:18.3& 23.3 g plant^{-1}) at 60 and 90 DAS, respectively. This remained superior over rest of the treatment and soil application of Mo @ 1000 g ha^{-1} closely followed.

Highest number of nodules recorded in treatment (T_3) seed treatment with Mo @ 6 g kg^{-1} of seed (44.2 and 63.5) at 30 and 45 DAS and it was on par with the treatment soil application of Mo @ 1000 g ha^{-1} (44.5 and 61.5). Significantly, lowest number of root nodules recorded in treatment (T_{10}) where no molybdenum application was done (35.5 and 48.7).

Table 2: Leaf area, Leaf area index, plant dry weight of soybean as influenced by different method and level of molybdenum application.

Treatments	Leaf area index				Plant dry weight (g plant^{-1})			
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1 - Seed treatment with Mo @ 2 g kg^{-1} of seeds	1.17	1.74	1.42	0.95	4.41	13.16	17.93	20.28
T_2 - Seed treatment with Mo @ 4 g kg^{-1} of seeds	1.23	1.94	1.62	1.15	4.49	14.81	19.54	21.89
T_3 - Seed treatment with Mo @ 6 g kg^{-1} of seeds	1.31	2.03	1.74	1.27	5.30	18.33	23.30	25.65
T_4 - Foliar application of Mo at 0.025%	1.16	1.75	1.43	0.92	4.16	11.94	18.37	20.73
T_5 - Foliar application of Mo at 0.05%	1.16	1.82	1.42	0.94	4.23	14.91	18.94	21.29
T_6 - Foliar application of Mo at 0.1%	1.18	1.83	1.45	0.96	4.30	13.67	20.25	22.60
T_7 - Soil application of Mo @ 500 g ha^{-1}	1.20	1.77	1.45	0.98	4.27	13.81	20.29	22.64
T_8 - Soil application of Mo @1000 g ha^{-1}	1.28	1.92	1.68	1.21	4.49	15.89	21.74	24.09
T_9 - Soil application of Mo @1500 g ha^{-1}	1.22	1.75	1.45	0.99	4.37	15.33	19.62	21.97
T_{10} - Control (No Mo application)	1.11	1.53	1.22	0.82	4.11	12.54	17.01	19.36
S.Em.±	0.05	0.06	0.05	0.05	0.23	0.89	0.51	0.58
CD 5%	NS	0.18	0.15	0.16	NS	2.66	1.51	1.73

Table 3: Total number of root nodules and Yield attributes of soybean as influenced by different method and level of molybdenum application.

Treatments	Total number of root nodules		Effective root nodules		No. of pod/plant	No. of grains /Pod	Test weight (g)	Seed yield/plant (g)
	30 DAS	45 DAS	30 DAS	45 DAS				
T_1 - Seed treatment with Mo @ 2 g kg^{-1} of seeds	38.66	52.67	33.66	47.33	38.06	3.07	13.77	14.71
T_2 - Seed treatment with Mo @ 4 g kg^{-1} of seeds	43.10	58.93	41.00	52.75	43.52	3.16	13.94	15.91
T_3 - Seed treatment with Mo @ 6 g kg^{-1} of seeds	44.17	63.53	43.01	61.30	56.87	3.51	14.28	17.14
T_4 - Foliar application of Mo at 0.025%	36.44	50.78	32.63	44.10	34.27	2.93	13.73	13.82
T_5 - Foliar application of Mo at 0.05%	37.64	51.00	32.90	45.33	37.99	3.00	13.74	14.08
T_6 - Foliar application of Mo at 0.1%	38.04	53.49	34.31	49.20	38.73	3.10	13.81	14.74
T_7 - Soil application of Mo @ 500 g ha^{-1}	42.57	54.67	38.90	50.40	42.80	3.13	13.87	15.41
T_8 - Soil application of Mo @1000 g ha^{-1}	44.50	61.53	42.70	59.13	54.28	3.47	14.05	16.61
T_9 - Soil application of Mo @1500 g ha^{-1}	44.34	57.13	40.46	52.70	42.93	3.14	13.92	15.80
T_{10} - Control (No Mo application)	35.54	48.67	28.85	41.07	33.53	2.73	13.69	13.75
S.Em.±	2.13	2.54	1.89	2.61	3.32	0.08	0.11	0.35
CD 5%	6.35	7.54	5.62	7.77	9.88	0.22	NS	1.06

Yields attribute and soybean yield

The response of yield attributes of soybean significantly influenced by Mo application, higher number of pods per plant, grains per pod, test weight were registered with seed treatment with Mo @ 6 g kg^{-1} of seed was recorded (56.9, 3.5 and 14.2g), respectively. While it remained was on par with the treatment soil application of Mo @ 1000 g ha^{-1} (T_8) (54.3, 3.7 and 14.05 g) and lowest yield attributes are noted in in control T_{10} treatment (33.5, 2.7 and 13.7g). Significantly higher seed yield per plant was recorded in treatment with (T_3) Seed treatment with Mo @ 6 g kg^{-1} of seed (14.14 g) and it was on par with (T_8) soil application of Mo @ 1000 g ha^{-1} (13.6g) and lowest number of seed yield per plant was recorded in control (T_{10}) (10.8 g).

The grain yield of soybean varied significantly with different methods and levels of molybdenum application (Table. 4.10). Highest grain yield of soybean was recorded in Seed treatment with Mo @ 6 g kg^{-1} of seed (1695.02 kg ha^{-1}) and it was on par with soil application @ 1000g (T_8) (1671.60). Lowest yield was recorded in control (POP alone) (1445.32 kg ha^{-1}). Compare to (T_{10}) control seed yield was increased by 17.2% in seed treatment and in soil application increased by 15.6%. Seed treatment of Mo @ 6 g kg^{-1} of seed recorded higher seed yield (1695.02 kg ha^{-1}) was recorded (T3), among foliar application of 0.1% Mo @ 20 DAS was recorded higher yield (1511.67 kg ha^{-1}) (T_6).

Similarly, highest haulm yield (2520 kg ha^{-1}) was obtained in T_3 followed by T_8 (2439.08). control (POP alone) (2236.34 kg ha^{-1}) and foliar application of Mo 0.025% @ 20 DAS (2261.67 kg ha^{-1}) recorded significantly lower haulm yield compared seed treatment and soil application. Highest biological yield of soybean (4215.02) was realized with treatment (T_3) closely on par with (T_8) (4110.68). Influence of foliar application of Mo on soybean was least, but application of Mo 0.1% @ 20 DAS (T_6) recorded higher biological yield (3870.0 kg ha^{-1}). Seed treatment and Soil application of Mo found better than foliar application for both growth and yield of soybean. Harvest index of soybean varied from 39.3 per cent to 40.2 and did not differ significantly. However, relatively higher harvest index was registered with treatment (T_8) Soil application of Mo @ 1000 g ha^{-1} (40.19).

Table 4: Grain, haulm yield and harvest index of soybean as influenced by different method and level of molybdenum application.

Treatments	Grain yield (kg ha-1)	Haulm yield (kg ha-1)	Biological yield (kg ha^{-1})	Harvest index (%)
T_1 - Seed treatment with Mo @ 2 g kg^{-1} of seeds	1506.25	2341.32	3847.57	39.15
T_2 - Seed treatment with Mo @ 4 g kg^{-1} of seeds	1618.16	2412.67	4030.83	40.15
T_3 - Seed treatment with Mo @ 6 g kg^{-1} of seeds	1695.02	2520.00	4215.02	40.19
T_4 - Foliar application of Mo at 0.025%	1452.33	2261.68	3714.01	39.09
T_5 - Foliar application of Mo at 0.05%	1454.58	2315.35	3769.93	38.59
T_6 - Foliar application of Mo at 0.1%	1511.67	2358.30	3869.97	39.06
T_7 - Soil application of Mo @ 500 g ha^{-1}	1563.35	2379.33	3942.68	39.66
T_8 - Soil application of Mo @1000 g ha^{-1}	1671.60	2439.08	4110.68	40.68
T_9 - Soil application of Mo @1500 g ha^{-1}	1616.67	2407.28	4023.95	40.18
T_{10} - Control (No Mo application)	1445.32	2236.34	3681.66	39.27
S. Em.±	39.87	51.96	58.28	39.15
CD 5%	108.48	154.4	176.2	NS

Discussion

Growth attributes

The improved plant height recorded with molybdenum seed treatment @ 6 g might be due to the effect of Moon increased nitrogen fixation and photosynthesis and increased availability of nutrients especially nitrogen and its role in increasing cell division and cell elongation. Similar results were reported by Spandana (2016) [11], Jyothi *et al*. (2015) [4] in soybean. Growth and development of any crop depends on assimilatory surface in terms of number of branches, number of leaves. Higher number of branches in seed treatment with Mo @ 6 g kg^{-1} of seed might have increased metabolic processes in plants resulting in greater meristematic activity and apical growth, which increased plant height and thereby formation of higher number of leaves per plant, ultimately resulting in improved photosynthetic surface area of the plant and LAI Similar result was noticed by Pareek (2005) [9] in cowpea with application molybdenum 1kg ha^{-1}. Mo is a constituent of enzyme nitrogenase, which is essential for the process of symbiotic nitrogen fixation and is also present in the enzyme nitrate reductase responsible for reduction of nitrates to ammonia in plant resulting into increased amino acids and protein synthesis in cell of plant, causing better growth and development. These results corroborate the findings of Gad and Kandil (2013) [3], Khan *et al*., (2014) [6] and Yadav *et al*. (2017) [14]. Dry matter accumulation (DMA) in our experiment is cumulative effect of a symbiotic nitrogen fixation, and vigorous growing regions, meristematic tissues ultimately increasing cell division and multiplication there by accumulating more dry matter. It could be observed by results in plant height and number of branches in similar treatment. Similarly, at 45 DAS higher effective root nodule and nodule weight in this treatment might have contributed to higher DMA at 60 DAS, these results were supported by Spandana (2016) [11].

Our experiment recorded 24.3 and 30.5% higher number of root nodules in Mo seed treatment (6 g/ha) at 30 and 45 DAS respectively) over control. Role of molybdenum coupled with higher initial energy availability for better root growth and development with increasing level of molybdenum. This leads higher nodulation and it reflecting in higher nitrogen fixation. It also might be due to synergistic effect of Mo with phosphorus, which enhances the phosphorus availability to plants and the stimulatory effect of phosphorus on plant metabolic processes. Since, phosphorus is the major constituent of cell nucleus and growing root tips, which helps in cell division and root elongation thus reflecting in increased nodule number and nodule size. Pareek (2005) [9] and Chowdhury *et al.*, (1998) [17] observed similar results of increased the number of total and effective nodules per plant, fresh weight of effective nodules per plant at 40 DAS. Gad and Kandil (2013) [3], Khan *et al*., (2014) [6] and Yadav *et al*. (2017) [14] also attribute to beneficial effect of molybdenum on root nodule formation and nitrogen fixation under various pulses and legumes.

Yield attributes and Yield

Our experimental results indicated differential response of treatments with respect to yield parameters, for application of molybdenum. Combined effect of growth as well as yield attributing characters reflected on seed yield of soybean. Higher number of pods was probably due to the improved growth parameters and nodulation. These results are in accordance with Noor *et al.* (1997) [8] and Karpagam and Rajesh (2014) [5]. Seed treatment @ 6 g could be ascribed to the adequate availability of micro and macro nutrients that helped in promoting better branching and nodulation by influencing cell division and cell elongation in meristematic cells there by increasing the sink in terms of flowering and seed setting Pareek (2005) [9]. The increase in yield attributes was probably due to source and sink relationship. The improvement in photosynthesis and carbohydrate metabolism resulting into greater formation of photosynthates and metabolites in source and later on translocated in the newly formed sinks *i.e.*, reproductive structures (flowering and seed setting) which ultimately increased pods per plant and test weight (Table 4 and Fig 1).

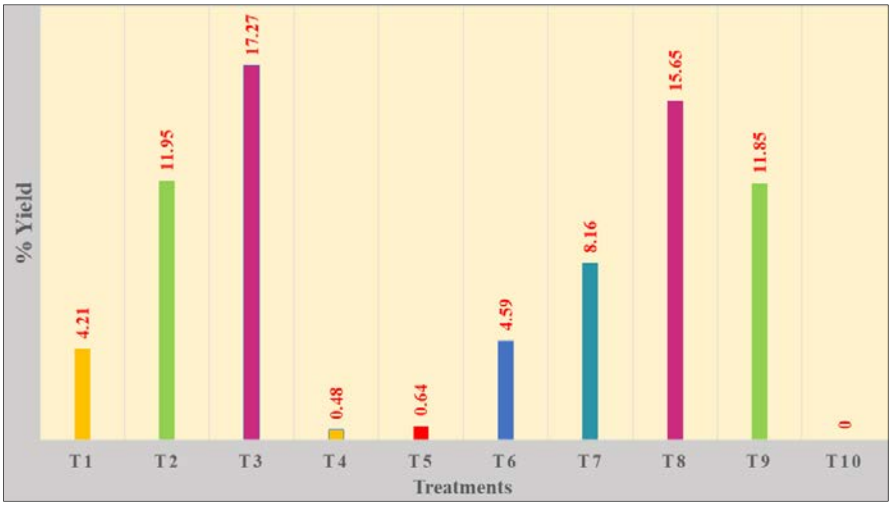

Fig 1: Percent increment in yield of soybean influenced by methods and levels of Mo

Higher seed yield per plant with application of seed treatment with Mo @ 6 g kg^{-1} of seed due to adequate nutrition that favored better growth parameters (plant height, number of The substantial increase in seed and haulm yield with application of molybdenum might be due to increased growth characters like nodulation, plant height and yield attributing characters *viz;* pods per plant, seeds per pod might have enhanced the seed yield significantly.

Conclusion

Based on the results obtained in this investigation it can be concluded that, the response of soybean to Mo was significant with methods and levels. Seed treatment with Mo @ 6 g kg^{-1} of seeds had significant effect on growth, nodules, yield parameters and yield of soybean. Soil application of 1000g Mo/ha could also be followed for higher growth and yield. Overall the study concluded, seed treatment of 6 g molybdenum kg^{-1} of seed along with PoP can be recommended as suitable practice compare to application of PoP alone.

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Conflict of interest

The authors declare no competing interests.

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