Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2024; 13(4): 44-49
Received: 03-05-2024
Accepted: 05-06-2024

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Enhancing soybean growth and yield: Investigating the effects of different molybdenum levels combined with organic and inorganic fertilizers

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DOI: https://doi.org/10.22271/phyto.2024.v13.i4a.14994

Abstract
The study at Sher-e-Bangla Agricultural University (Nov 2022 to Mar 2023) evaluated the impact of varying molybdenum levels, organic, and inorganic fertilizers on soybean growth and yield using a Randomized Complete Block Design (RCBD) with three replications. Results showed significant nutrient management effects on all parameters except the harvest index for BARI soybean 6. The best results were achieved with a treatment combining 75% recommended chemical fertilizer (RCF), 2 kg/ha of molybdenum, and 3 t/ha of cow dung T8 Treatment At 60 DAS, T8 yielded the highest plant height (51.82 cm), branches (5.82), pods (42.65), seed yield (2.40 t/ha), Stover yield (2.80 t/ha), and biological yield (5.20 t/ha), with a harvest index of 46.15%. The lowest values resulted in T_1 (no fertilizer) treatment. This suggests that integrating molybdenum with organic and inorganic fertilizers can boost soybean growth and yield while reducing inorganic fertilizer use by up to 25%.

Keywords: Soybean, molybdenum, organic fertilizer, inorganic fertilizer, growth, yield

Introduction
Soybean (*Glycine max* L.) is one of the most cost-effective and nutritious crops in the world with high protein content, and a great source of both oil and protein supplements (Mondal *et al.*, 2002) [1]. It is known as the "golden bean" in Bangladesh and is mostly used as fish and poultry feed. The growing fish and poultry sectors are driving up demand for it. It is celebrated as a pivotal crop of the 20th century due to its exceptional protein and oil content, earning it a status akin to a nutritional reservoir (Kim *et al.*, 2012) [2]. Despite its nutritional prowess, soybean contains antinutritional factors, notably trypsin inhibitors, yet its seeds boast an impressive composition comprising 42-45% protein, 22% edible oil, and 24-26% carbohydrates (Wadhawan *et al.*, 2021) [3]. Recognized for its abundance of essential amino acids, unsaturated fatty acids, and carbohydrates, soybean oil emerges as a cholesterol-free dietary staple, readily embraced for its health benefits (Saha and Mandal, 2019) [4]. Its global prominence is evidenced by its dominance, accounting for approximately 50% of total oilseed crop production worldwide, with tropical countries, including Bangladesh, increasingly integrating soybeans into their agricultural landscapes.

The insufficient soybean yield in Bangladesh can be attributed to various factors, including inadequate access to high-quality seeds and fertilizers, the utilization of local varieties for planting, improper timing of sowing, limited application of organic and inorganic fertilizers, adverse climatic conditions, and notably, a decline in soil organic matter (Miah and Mondal, 2017; Shakoor *et al.*, 2017) [5, 6].

Integrating both organic and inorganic fertilizers into the soil improves its chemical and physical attributes, which leads to higher crop yields (Pasha *et al.*, 2015) [7]. Nitrogen, phosphorus, and potassium (NPK) are necessary for numerous plant functions, with nitrogen boosting vegetative development, phosphorus supporting physiological processes, and potassium facilitating metabolism and protein synthesis (Pankaj *et al.*, 2016; Khan *et al.*, 2016; Zahoor *et al.*, 2017) [8-10]. Soybeans utilize both soil and atmospheric nitrogen, and their nitrogen requirements are complex (Ciampitti *et al.*, 2021) [11], To maintain soil health and maximize yields, careful fertilizer selection is required. While inorganic fertilizers supply nutrients rapidly for quick plant growth, organic fertilizers, such as compost and manure, improve soil health and microbial activity (Timilsena *et al.*, 2015) [12].

Both forms of fertilizers are necessary for delivering the macro and micronutrients needed to promote proper plant growth and development (Rashmi *et al*., 2020) [13].

Molybdenum is required for crucial enzymatic processes in plants, including nitrogen metabolism, nitrogen fixation, and nitrate absorption (Ansary, 2014) [14]. Its addition to soils can increase potassium, phosphorus, and crude protein levels, demonstrating its importance in plant growth (Manuel *et al*., 2018) [15]. Molybdenum's poor mobility inside plants limits its translocation under scarcity (Manuel *et al*., 2018; Ting Sun *et al*., 2013) [15, 16]. It improves yield quality and nodulation in legume crops by increasing plant height, branch and pod numbers, and seed production (Ting Sun *et al*., 2013) [16]. Integrating molybdenum with organic compost and inorganic fertilizers enhances soybean growth and yield. The experiment aimed to assess the impact of combining molybdenum with organic (cow dung) and inorganic fertilizers on soybeans' growth, yield, and productivity.

Materials and Methods

Experimental site

The field experiment occurred at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka, from November, 2022 to March, 2023. The experimental site is situated at 23°46' N latitude and 90°22' E longitude, with an elevation of 8.2 m above sea level, falling within the Agro-ecological Zone "AEZ-28" of Madhupur Tract. The area is characterized by Deep Red Brown Terrace Soils.

Soil and climate

The experimental field's soil exhibits a slightly acidic nature with low organic matter. The topsoil has a sandy loam texture, a pH of 6.16, and 0.69% organic carbon. The experimental zone experiences a sub-tropical climate with reduced rainfall and relatively low temperatures from October to March (rabi season). In contrast, the kharif season from April to September is marked by high temperatures, elevated humidity, and substantial rainfall with intermittent strong winds.

Planting material

The BARI Soybean-6 variety served as the planting material for this study which is developed by the Bangladesh Agriculture Research Institute (BARI) in Gazipur, Bangladesh. Key characteristics of BARI Soybean-6 include a plant height ranging from 50 to 55 cm, and each plant typically bears 50 to 55 pods. The pods themselves measure between 3 to 3.5 cm in length, and each pod contains a maximum of 2 to 3 seeds. The seeds are medium-sized with a cream-colored coat, and a hundred seeds weigh between 10 to 12 grams. The crop has a growth duration of 100 to 110 days. This variety is noted for its tolerance to the yellow mosaic virus (YMV).

Experimental design and layout

The study was designed according to the Randomized Complete Block Design (RCBD) with three replications. Each plot measured 2.5 meters by 2 meters, totaling 5 square meters, and there was a total of 24 plots. The experiment comprised 8 different treatments. The layout was established on November 25, 2022, with an inter-plot spacing of 0.75 meter and inter-block spacing of 1 meter. Plant spacing was carefully maintained at 30 centimeters between lines and 10 centimeters between individual plants.

Land preparation and sed sowing

On November 21, 2022, the research field embarked on its journey with the introduction of a power tiller. Following this, a seven-day sunbathing session set the stage for subsequent ploughing endeavors. Weeds and stubbles were meticulously eradicated from the research field, marking the completion of the land operation on November 22, 2022.

On November 28, 2022 seeds were sown. Prior to sowing, these seeds underwent treatment with Provax, a fungicide used to mitigate seed-borne diseases. The sowing process involved placing the treated seeds into furrows at a depth of 2-3 centimeters.

Experimental treatments

The experiment consists of single factor i.e. different doses of fertilizers. Detail of treatments is given bellow:

T_1= Control

T_2 = 100% RCF + 0kg/ha Mo + 0 t/ha cowdung T_3 = 100% RCF + 1kg/ha Mo+ 1 t/ha cowdung T_4 = 100% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung T_5 = 100% RCF + 2kg/ha Mo+ 3 t/ha cowdung T_6 = 75% RCF + 1kg/ha Mo+ 1 t/ha cowdung T_7 = 75% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung T_8 = 75% RCF + 2kg/ha Mo+ 3 t/ha cowdung

RCF=Recommended dose of fertilizer (N28P34K55S18B1.5 kg/ha) according to Fertilizer Recommended Guide-2018.

Fertilizer Application

In this study, fertilizers were administered based on specific treatments outlined as follows. The quantities of urea, triple superphosphate, muriate of potash, gypsum and boric acid required per plot were determined. The combined quantity of Compost, Urea, TSP, MoP, and Boric Acid was used as the initial dose during land preparation.

Methods of Data Collection

Ten plants were chosen randomly from each treatment and identified with tags for recording data on plant characteristics. Data on plant characteristics were collected every 20 days from sowing until harvest. Yield and factors contributing to yield were observed from the central section of the plots. Data was collected following growth (plant height, number of branches per plant) parameters, yield contributing (number of pods per plant, pod length, seeds per pod) parameters and yield (seed yield, stover yield, biological yield, harvest index) parameters.

Harvest index

The harvest index was determined by analyzing the seed and stover yields per hectare acquired from each individual plot. These yields were then converted into a percentage to ascertain the proportion of the total yield represented by the seed output.

$$\text{Harvest index} = \frac{\text{Economic yield (seed weight)}}{\text{Biological yield (total dry weight)}} \times 100$$

Statistical Analysis

The data of observation were analyzed using analysis of variance (ANOVA). The Statistics 10 computer program was employed for the statistical analysis of the data derived from the experiment's diverse parameters. Mean values for each parameter were computed, and an analysis of variance was conducted. To assess the significance of differences among treatment means, the Duncan Multiple Range Test was utilized at a 5% probability level.

Results and Discussion

Plant height (cm)

Plant height at different growth stages (20 DAS, 40 DAS, and 60 DAS) varied significantly across treatments (Table 1). The highest plant height was consistently observed in treatment T8 (75% RCF, 2 kg/ha Mo, 3 t/ha cow dung), with 26.58 cm at 20 DAS, 30.46 cm at 40 DAS, and

51.82 cm at 60 DAS, significantly outperforming other treatments. The control (T_1) had the lowest heights, with 16.43 cm, 21.67 cm, and 32.57 cm at the respective stages. These results indicate that the combination of reduced chemical fertilizer, adequate molybdenum, and cow dung significantly enhances plant growth. The synergistic effects of cow dung and molybdenum improve soil structure and nutrient availability, promoting better plant development.

Integrating organic and inorganic fertilizers is crucial for optimal plant growth and sustainable agriculture. The combined use of reduced chemical fertilizers, molybdenum, and cow dung enhances plant height, reduces chemical dependency, improves soil health, and promotes sustainability. Studies by Biswas (2012) [17] and Dozet *et al*., (2016) [18] highlight molybdenum's essential role in plant growth. Deshmukh *et al*., (2018) [19] found that organic compost boosts nutrient uptake and soybean growth. Verma *et al*., (2018) [20] and Murthy *et al*., (2017) [21] emphasize the benefits of organic manures in improving productivity and profitability, especially in acidic soils.

Table 1: Effect of molybdenum with organic and inorganic fertilizer on plant height of soybean.

Treatment	Plant height (cm)		
	20 DAS	40 DAS	60 DAS
T_1	16.43 g	21.67 g	32.57 g
T_2	18.24 f	23.47 f	35.77 f
T_3	19.88 e	24.88 e	38.70 e
T_4	22.58 c	26.06 d	42.76 d
T_5	23.10 c	27.15 c	45.64 c
T_6	21.24 d	25.56 de	40.16 e
T_7	24.47 b	28.58 b	48.48 b
T_8	26.58 a	30.46 a	51.82 a
LSD 0.05	0.7007	0.7214	2.4825
CV%	4.25	7.45	8.23

T_1= Control, T_2 = 100% RCF + 0kg/ha Mo+ 0 t/ha cowdung, T_3 = 100% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_4 = 100% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_5 = 100% RCF + 2kg/ha Mo+ 3 t/ha cowdung, T_6 = 75% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_7 = 75% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_8 = 75% RCF + 2kg/ha Mo+ 3 t/ha cowdung

Number of branches per plant

Number of branches varied significantly across treatments (Table 2). The range of the number of branches among the treatments was 2.42 to 5.82, indicating significant variation due to different fertilization regimes. The highest number of branches was observed in T8 (75% RCF + 2 kg/ha Mo + 3 t/ha cowdung) with 5.82 branches. The lowest number of branches was observed in the control (T_1) with 2.42 branches.

The availability of nutrients from both organic and inorganic sources can influence the number of branches per plant, leading to enhanced nutrition absorption, cell division, and overall growth. Falodun *et al*. (2015) [22] found that organic and inorganic fertilizers increased the number of branches and leaves per soybean plant. The favorable effects of molybdenum on vegetative growth and the accumulation of substances that promote growth, resulting in the normal growth and development of the soybean plant, maybe the cause of the increased number of primary branches per plant. Rizvi (2014) [23] investigated and found that 1.5 kg Mo ha^{-1} produced the largest number of branches per plant (3.42).

Number of pods per plant

The quantity of pods differed notably among the various treatments, as illustrated in Table 2. Pod numbers ranged from 21.83 to 42.65, with Treatment 8 (T_8) showing the highest count and Treatment 1 (T_1) serving as the control group, displaying the lowest count due to the absence of fertilizer application. Treatment 8 (T_8) recorded the highest pod count of 42.65, while Treatment 1 (T_1), acting as the control group without any fertilizer, exhibited the lowest pod count at 21.83. Soybean pods per plant may vary due to the increased availability of micronutrients from organic and inorganic sources, resulting in rapid metabolic processes and improved nutritional absorption. This study supports the findings of Morya *et al*., (2018) [24], who found that using inorganic fertilizer and organic vermicompost led to a considerable increase in soybean pods per plant. According to Biswas *et al*., (2012) [17], utilizing 2 kg Mo ha^{-1} resulted in the highest number of pod yields (39.67) in soybean plants.

Pod length (cm)

Pod lengths varied significantly among treatments, with measurements ranging from 3.10 cm to 4.61 cm. Treatment T_8, consisting of 75% RCF with 2 kg/ha Mo and 3 t/ha Cowdung, had the longest pods at 4.61 cm, while Treatment T_1, functioning as the control, had the shortest pod length at 3.10 cm (Table 2).

Increased pod length may be due to enzyme activities that regulate blooming, pod formation, growth, and development (Awasthi *et al*., 2020) [25]. According to Ansary (2014) [14], the use of molybdenum fertilizer considerably affects soybean pod length. In his experiment, 1.5 kg of Mo ha^{-1} resulted in the longest pod (5.43 cm).

Table 2: Effect of molybdenum with organic and inorganic fertilizer on number of branches per plant, number of pods per plant, pod length (cm) and seed per pod of soybean.

Treatment	Number of branches per plant	Number of pods per plant	Pod length (cm)	Seed per pod
T_1	2.42 f	21.83 f	3.10 g	2.11 f
T_2	3.30 e	25.47 e	3.4 f	2.77 ef
T_3	3.81 de	28.57 de	3.63 e	3.19 de
T_4	4.42 cd	33.97 c	3.92 cd	3.61 cd
T_5	4.71 bc	36.64 c	4.12 c	3.90 bc
T_6	4.23 cd	31.37 d	3.76 de	3.42 cde
T_7	5.21 ab	40.45 b	4.37 b	4.32 ab
T_8	5.82 a	43.65 a	4.61 a	4.90 a
LSD 0.05	0.6858	2.07	0.209	0.6971
CV%	4.25	3.59	3.94	5.74

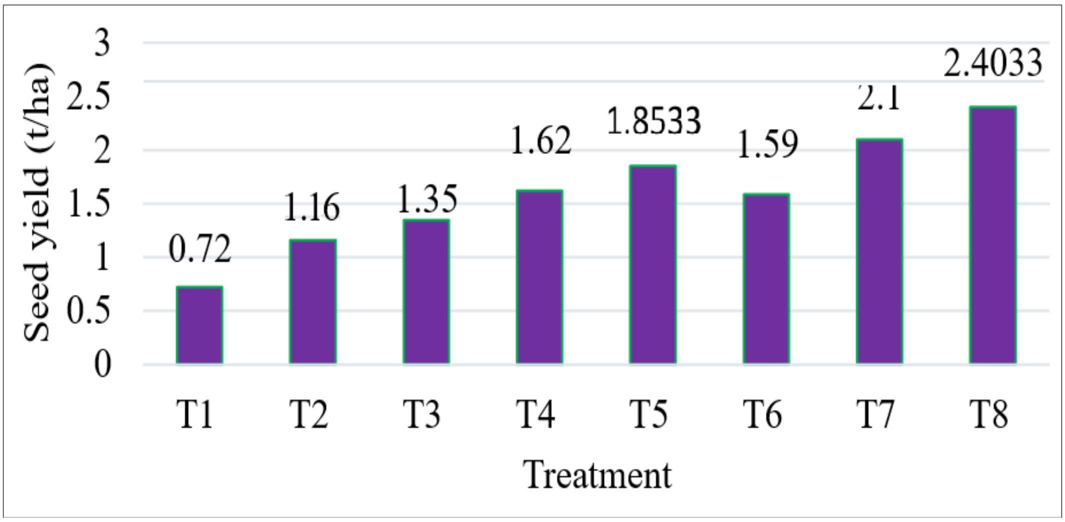
T_1 = Control, T_2 = 100% RCF + 0kg/ha Mo+ 0 t/ha cowdung, T_3 = 100% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_4 = 100% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_5 = 100% RCF + 2kg/ha Mo+ 3 t/ha cowdung, T_6 = 75% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_7 = 75% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_8 = 75% RCF + 2kg/ha Mo+ 3 t/ha cowdung

Number of seeds per pod

Seed per pod values varied across treatments, ranging from 2.11 (Treatment T_1) to 4.90 (Treatment T8), indicating substantial differences in pod yield depending on the treatment conditions. Treatment T8 exhibited the highest seed

per pod yield, suggesting that the combination of 75% RCF, 2kg/ha Molybdenum, and 3 t/ha cow dung is most effective in maximizing seed production per pod (Table 2).
Khander *et al*. (2013) [26] observed that applying organic and inorganic fertilizers, as well as micronutrients, promotes optimal soil conditions, leading to increased nutrient availability and improved soybean yield. The findings conform with those already reported by Morya *et al.,* (2018) [24] and Sushil *et al.,* (2015) [27].

Seed yield (t/ha)
Seed yield varied significantly across treatments (Figure 1). The range of seed yields observed across the treatments was from 0.72 t/ha to 2.40 t/ha. The highest seed yield was recorded in T_8 (2.40 t/ha), which involved 75% of the recommended chemical fertilizer (RCF), 2 kg/ha Mo, and 3 t/ha cow dung. The control treatment (T_1) yielded the lowest seed output, which is expected as it did not receive any fertilization. T_7 also showed a high yield (2.10 t/ha), which was significantly greater than the treatments with 100% RCF, such as T_2 (1.16 t/ha), T_3 (1.35 t/ha), T_4 (1.62 t/ha), and T_5 (1.85 t/ha).
This could be due to adequate nutrient supply from both organic and inorganic sources at the proper growth phases, resulting in optimal dry matter distribution from source to sink throughout the plant's reproductive phase. This, in turn, most certainly helped to boost soybean seed yield. Morya *et al*. (2018) [24] discovered that the combination of organic and inorganic fertilizers had a significant impact on soybean seed yields. Rizvi (2014) [23] and Valenciano *et al*., (2010) [28] observed that an increase in molybdenum levels positively influenced various yield-contributing traits. Similar findings conformed with those already reported by Joshi *et al.,* (2013) [29] And Shwetha *et al.,* (2012) [30].



T_1= Control, T_2 = 100% RCF + 0kg/ha Mo+ 0 t/ha cowdung, T_3 = 100% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T4 = 100% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_5 = 100% RCF + 2kg/ha Mo+ 3 t/ha cowdung, T_6 = 75% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_7 = 75% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung, T_8 = 75% RCF + 2kg/ha Mo+ 3 t/ha cowdung

Fig 1: Effect of molybdenum with organic and inorganic fertilizer on seed yield of soybean.

Stover yield (t/ha)
Stover yield varied significantly across treatments, ranging from 0.85 t/ha to 2.80 t/ha (Table 3). The lowest yield was observed in T_1 (0.85 t/ha), representing the control treatment without fertilizer application. Conversely, the highest yield was achieved in T_8 (2.90 t/ha), which received 75% of the recommended chemical fertilizer (RCF), in addition to 2 kg/ha of Molybdenum (Mo) and 3 t/ha of cow dung.
Patil and Udmale (2016) [31] found that soybean stover yields increased with varied amounts of organic and inorganic fertilizers, similar to the yield obtained with solely inorganic fertilizer, suggesting that higher concentrations of phosphorus (P) and sulfur (S) in the applied fertilizers potentially enhance plant metabolism, chlorophyll formation, and photosynthesis, aligning with the findings of Dikshit and Khatik (2008) [32]. Biswas *et al.* (2012) [17] found the highest stover yield (2767 kg ha^{-1}) from 2 kg Mo ha^{-1}.

Biological yield (t/ha)
The biological yield ranges from 1.39 to 5.20 tons per hectare across the treatments, varied significantly among treatments (Table 3). Treatment T_8, which comprises 75% RCF, 2kg/ha Mo, and 3 tons/ha cow dung supplementation, exhibits the highest yield of 5.3033 tons/ha, while T_1, the control treatment without any fertilizer application, records the lowest yield of 1.39 tons/ha.
Treatments T_2 to T_8 demonstrate progressively higher biological yields with increased levels of Mo and cowdung. Among these, T_8, which received a combination of 75% RCF, 2 kg/ha Mo, and 3 t/ha cowdung, achieved the highest biological yield of 5.20 t/ha. Zakaria *et al.* (2014) [33] demonstrated that a notable impact on biological yield (2.97 ton/fed) was noted in soybean plants treated with (30 kg P2O5 fed-1 + 0.5 kg Mo + 20 mg L-1 Fe). This study supports the findings of Awasarmal *et al*., (2013) [34], who discovered that the application of organic and inorganic fertilizers considerably affects soybean biological yield. Naik *et al*., (2019) [35], Murthy *et al*., (2017) [21], and Kanwar with Sharma (2014) [36] also supported these studies.

Table 3: Effect of molybdenum with organic and inorganic fertilizer on Stover yield (t/ha), biological yield (t/ha) and harvest index % of soybean.

Treatment	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index %
T_1	0.85 g	1.39 f	45.98
T_2	1.28 f	2.44 e	47.58
T_3	1.46 ef	2.81 e	48.24
T_4	1.91 cd	3.53 d	45.84
T_5	2.21 bc	4.06 c	45.52
T_6	1.74 de	3.33 d	47.87
T_7	2.52 ab	4.62 b	45.51
T_8	2.80a	5.20a	46.15
LSD 0.05	0.3878	0.4911	5.021
CV%	3.07	8.44	7.90

T_1 = Control, T_2 = 100% RCF + 0kg/ha Mo+ 0 t/ha cowdung, T_3 = 100% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_4 = 100% RCF + 1.5kg/ha Mo + 2 t/ha cowdung, T_5 = 100% RCF + 2kg/ha Mo+ 3 t/ha cowdung, T_6 = 75% RCF + 1kg/ha Mo+ 1 t/ha cowdung, T_7 = 75% RCF + 1.5kg/ha Mo + 2 t/ha cowdung, T_8 = 75% RCF + 2kg/ha Mo+ 3 t/ha cowdung

Harvest index

The data range of harvest index values spans from 45.51 to 48.24, indicating variability in treatment effects on crop yield efficiency, varied significantly among treatments (Table 3). Among the treatments, the highest harvest index value of 48.24 was observed in T_3 (100% RCF + 1kg/ha Mo+ 1 t/ha cowdung), while the lowest value of 45.51 was recorded in T_7 (75% RCF + 1.5kg/ha Mo+ 2 t/ha cowdung).

These findings imply that for soybean cultivation, the addition of Molybdenum, whether through organic sources like cow dung or inorganic fertilizers, did not significantly affect the harvest index. Similar findings were observed by Biswas *et al*., (2012) [17].

Conclusion

The findings presented in the research and the subsequent discussion can be summarized as follows. The combine application of organic and inorganic fertilizers along with Mo increased the plant height, number of brunches per plant, number of pods per plant, number of seeds per pod, length of pods, seed yield, Stover yield, biological yield and harvest index. Investigating the efficacy of a combination involving 75% RCF, 2 Kg/ha Molybdenum, and 3 t/ha cowdung. This combination has the potential to increase soybean production. Expanding studies on Molybdenum with organic and inorganic fertilizer management to assess the growth and yield outcomes of soybean (BARI soybean 6) cultivation across various Agro ecological zones (AEZ) in Bangladesh. Understanding how different regions respond to Molybdenum with organic and inorganic fertilizer management approaches can provide valuable insights into regional variability and optimize soybean production strategies accordingly.

Acknowledgement

We would like to thank Md. Sabbir Hossain and Professor Mst. Afrose Jahan for their valuable contribution and technical support throughout the journey.

Conflict of Interest

All authors declared that they have no conflict of interest.

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