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Enhancing Soybean Growth and Yield through Improved Soil Fertility and Increased Chlorophyll Content

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ABSTRACT

This study aimed to evaluate the effect of soil fertility levels on the growth, chlorophyll content, and yield of soybeans at the BINA substation in Barisal. The research was conducted using Binasoybean-3 in a randomized complete block design (RCBD) with three replications. Four different soil fertility treatments were applied: F0 (no fertilizer), F1 (Rhizobium inoculation), F2 (NPK fertilizer), and F3 (Organic matter, cow dung at 2 tons ha-1). Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) were supplied through urea, triple super phosphate, and muriate of potash. Plants that did not receive any fertilizer had the lowest chlorophyll content, while plants treated with NPK showed the highest chlorophyll content, which was 21.78% higher than the control. This higher chlorophyll level in NPK-treated plants contributed to superior total dry mass (TDM) accumulation at both 80 and 90 days after sowing (DAS), with an increase of 60.83% and 81.49%, respectively, compared to the control. The maximum absolute growth rate was observed in NPK-treated plants at both 80 and 90 DAS. Furthermore, key yield-related traits, including the number of branches, pods, grains per pod, and 1000-grain weight, were highest in NPK-treated plants. As a result, the grain yield in NPK-treated plants was 97.46% higher than the control. These findings indicate the essential role of adequate NPK fertilization in maximizing soybean grain yield, as it enhances chlorophyll production, which in turn improves yield and plant growth.

Keywords: Soybean, Chlorophyll, Fertilizer, Growth rate, Yield factors, Grain yield

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Introduction

Soybeans are a significant source of essential nutrients and bioactive compounds, including various phenolic compounds and free radicals, which are associated with their antioxidant properties [1-3]. These compounds contribute to numerous health benefits, such as reducing the risks of certain cancers [4-6], lowering cholesterol levels, and decreasing cardiovascular disease risks [7]. Additionally, soybeans help prevent osteoporosis and alleviate post-menopausal symptoms [8]. Soybeans also provide amino acids that are typically lacking in grain-based diets for livestock and poultry [9]. Because of these health advantages, soybeans are in high demand for both human consumption and animal feed, making them a valuable commodity in the food processing and agriculture industries. Moreover, they have been used to improve the nutritional status of rural communities, particularly through fortification in local dishes [10, 11]. Consequently, soybeans are highly sought after across the globe, including in Bangladesh.

In Bangladesh, soybean production is mainly concentrated in the Bhola and Noakhali districts. However, many farmers are reluctant to cultivate and consume soybeans, primarily because of limited awareness about the benefits and inadequate access to improved seed varieties and agricultural practices, including proper fertilizer use. In particular, the application of phosphate and inoculum fertilizers is crucial for improving plant growth, chlorophyll content, and soybean yield [12]. Chlorophyll content is a key determinant of plant growth, directly influencing photosynthesis and overall crop productivity [13]. Rhizobium inoculation improves nitrogen fixation in soybeans, which boosts their yield [14-16]. Phosphorus, especially, is essential for seed development and yield [17]. Fertilizers containing nitrogen, phosphorus, and potassium not only promote nutrient uptake but also enhance root growth, support nodule formation, correct nitrogen deficiencies, and aid in seed maturation [18]. Prior research has highlighted the benefits of integrated soil fertility management (ISFM), combining organic fertilizers with phosphorus to improve plant health and increase soybean yield [19-22]. However, little research has been conducted on the effects of these practices on chlorophyll content, growth, and seed yield. Our research aims to examine the influence of various soil fertility conditions on chlorophyll content, plant growth, and yield in soybean crops.

Materials and Methods

A field experiment was carried out during the Rabi season of 2022 at the BINA sub-station, located in Barisal, Bangladesh. The coordinates of the site are 22.8162° N latitude and 90.3137° E longitude, with an altitude of 2 meters above sea level. The region experiences alternating cold and hot seasons. The experimental design followed a randomized complete block design (RCBD) with 3 replications. Four different treatments were applied to the Binasoybean-3 crop field: F0 (no fertilizer), F1 (Rhizobium inoculum), F2 (NPK fertilizer), and F3 (cow dung at 2 tons per hectare). Soybean seeds were sown on January 5th, 2022, in unit plots of 3 m × 2.5 m, maintaining a 30 cm spacing between rows. For treatment F1, the seeds were inoculated with Rhizobium biofertilizer before sowing. In the F2 treatment, each plot received urea (86.95 kg/ha), triple super phosphate (TSP) (66.67 kg/ha), and muriate of potash (MoP) (100 kg/ha). In treatment F3, organic cow dung was applied at a rate of 2000 kg per hectare.

The chlorophyll content in the leaves was measured using a SPAD-502 chlorophyll meter (Minolta, Japan), which assesses nitrogen levels by measuring the light transmission through the leaves at wavelengths of 650 and 940 nm. This device calculates an average of both wavelengths, providing a SPAD value for each measurement. After seventy days of sowing, plant samples were harvested at 10-day intervals for total dry and growth rate matter determination. Five plants per plot were collected, oven-dried at 70 ± 2 °C, and used to calculate the absolute total dry mass and growth rate. The absolute growth rate was determined by the increase in plant dry weight over a specified period, following the formula by Hunt [23, 24]:

$$\text{Absolute growth rate } = \frac{\text{W2} - \text{W1}}{\text{T2} - \text{T1}} \tag{1}$$

Where W1 is the dry weight at the initial time, W2 is the dry weight at the final time, T1 is the initial time, and T2 is the final time.

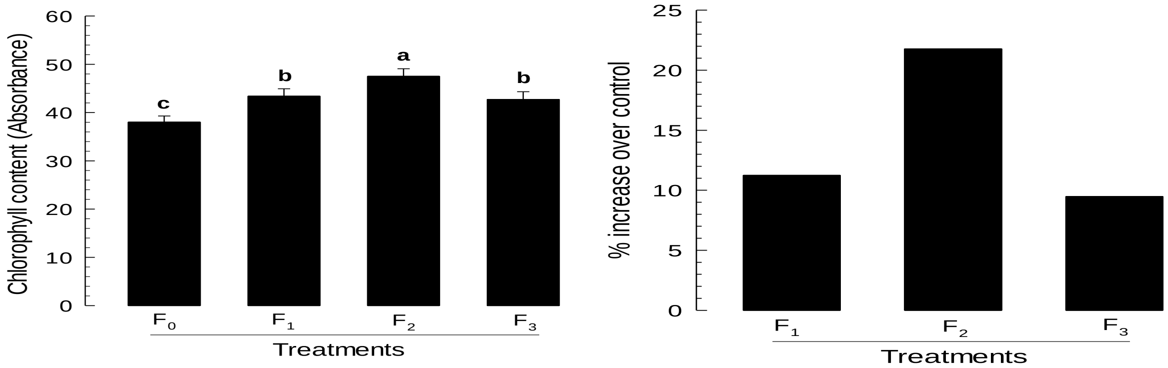
Upon reaching physiological maturity, five plants from each plot were harvested to record yield-related parameters. Additionally, a 1 m² quadrat was used to determine the yield per plot, which was then converted to tons per hectare. All data were analyzed using the SPSS software, employing analysis of variance (ANOVA). Duncan's Multiple Range Test at a 5% significance level was applied to compare treatment means.

Results and Discussion

The chlorophyll content in soybean leaves is influenced by the NPK levels in the soil. Measurements were taken using a Chlorophyll Meter SPAD-502 Statistical analysis ($P > 0.05$) confirmed that NPK availability plays a significant role in determining chlorophyll concentration.

Among the tested treatments, the highest chlorophyll content was observed in soybean plants treated with NPK, which showed a statistically significant difference compared to other treatments. This was followed by plants treated with Rhizobium and organic matter, while the lowest chlorophyll content was recorded in the control group (39.03) **(Figure 1a)**.

Additionally, the percentage increase in chlorophyll content relative to the control was assessed. The highest increase (21.78%) was observed in NPK-treated plants, followed by Rhizobium-treated and organic matter-treated plants **(Figure 1b)**. These findings indicate a direct correlation between higher NPK levels and enhanced chlorophyll content in soybean leaves. Similar results have been reported by Wamalwa *et al*. [25] and Pingale and Amrutkar [26], who observed an increase in chlorophyll content in finger millet leaves with higher NPK application.



a) b)

Figure 1. Impact of soil fertility on chlorophyll enhancement in leaves; a) chlorophyll content measured in SPAD units, and b) percentage increase compared to the control group; distinct letters above standard deviation bars indicate statistically significant differences among the means at a type I error rate of 0.05 (LSD test).

Impact of NPK on total dry mass accumulation

The accumulation of total dry mass (TDM) in Bina soybean-3 varied across different soil fertility treatments, showing a significant increase (P > 0.05) as the plant advanced in age. At 70 DAS, the highest TDM accumulation was taken in Rhizobium-treated plants (33.87 g/plant), followed closely by those treated with NPK (30.59 g/plant) and organic matter (30.19 g/plant), while the control plants had the lowest value (24.80 g/plant) **(Figure 2)**.

At 80 DAS, plants treated with NPK exhibited the highest TDM (72.39 g/plant), whereas those receiving Rhizobium and organic matter showed slightly lower values (61.18 g/plant and 59.18 g/plant, respectively), with the untreated control group recording the lowest TDM (55.02 g/plant) **(Figure 2)**. A similar trend continued at 90 DAS. From 70 DAS onward, soybeans grown with NPK consistently demonstrated the greatest TDM accumulation at growth stages, with statistically significant differences from other treatments. These findings align with those of Mete *et al*. [27], who reported a higher biomass yield in soybeans following NPK application compared to organic matter treatments.

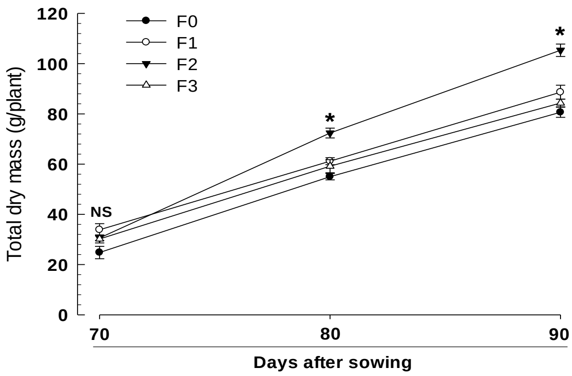


Figure 2. Variations in total dry mass (TDM) of soybeans at different growth stages under varying soil fertility treatments; asterisks indicate statistically significant differences among means at a 0.05 type I error level (LSD test).

Effect of soil N, P, and K levels on the absolute growth rate of soybean

The absolute growth rate (AGR) of soybean exhibited a significant (P > 0.05) increase as the plant matured, reaching its peak at 80 DAS before declining at 90 DAS across all treatments **(Figure 3a)**. The observed AGR increase at 80 DAS corresponded with the pod development phase. Among the treatments, plants receiving NPK had the highest AGR, while control plants displayed the lowest values. Specifically, the highest AGR values were recorded in NPK-treated plants at both 80 DAS (4.18 g/plant/day) and 90 DAS (3.29 g/plant/day), followed by Rhizobium-treated (3.32 and 2.86 g/plant/day) and organic matter-treated plants (3.32 and 2.86 g/plant/day). The lowest AGR was observed in untreated control plants (2.59 and 1.82 g/plant/day).

The relative increase in AGR due to treatments was assessed through the percentage rise compared to control plants **(Figure 3b)**. NPK-treated plants demonstrated the highest growth increase, with 64% at 80 DAS and 84% at 90 DAS, surpassing the Rhizobium treatment (28% and 60%, respectively) and organic matter treatment (28% and 64%, respectively). These findings highlight that higher chlorophyll levels are strongly linked to greater dry mass accumulation and an enhanced absolute growth rate. Similar observations were reported by Thompson *et al*. [28] and Haidar and Al-Shorafa [29], who identified a strong correlation between chlorophyll content and areal leaf mass (ALM) in soybeans.

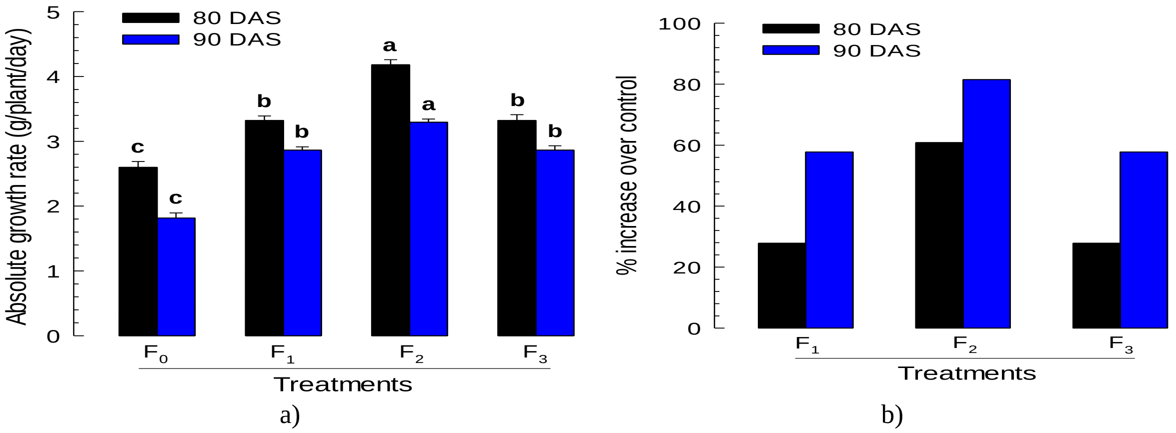


Figure 3. Impact of soil fertility levels on soybean growth over time; a) variations in absolute growth rate (AGR) at different growth stages, and b) percentage increase in growth rate relative to the control; distinct letters above standard deviation bars indicate statistically significant differences among means at a type I error rate of 0.05 (LSD test).

Impact of nutritional status on morphological traits and yield components

Variations in soil fertility significantly influenced the morphological traits and yield-related characteristics of soybean **(Table 1)**. The highest number of branches was observed in soybean plants treated with organic matter, which statistically was very similar to NPK-treated plants. In contrast, Rhizobium-treated plants exhibited the lowest branch count, which did not differ significantly from the untreated control. The highest pod count per plant was taken in NPK-treated plants, followed by those treated with organic matter, whereas the lowest pod count was discovered in Rhizobium-treated and control plants. Similarly, the greatest number of grains per plant was obtained from NPK-treated plants, while Rhizobium-treated and control plants showed no significant difference in this parameter.

Regarding seed size, as represented by 1000-grain weight, the largest seeds were found in NPK-treated plants, which showed no statistical difference from organic matter-treated plants. Meanwhile, the smallest seeds were recorded in Rhizobium-treated plants, which statistically were very similar to the control. The highest grain yield (2.33 tons ha^{-1}) was obtained from NPK-treated plants, attributed to their seed weight, superior pod count, and grain number per pod. Conversely, the lowest yield (1.18 tons ha^{-1}) was recorded in control plants. The yield increase over control was highest in NPK-treated plants (97.46%), followed by organic matter-treated plants (55.93%) and Rhizobium-treated plants (18.64%).

These findings suggest that an increase in chlorophyll content contributes to enhanced dry matter accumulation through improved photosynthesis. This, in turn, supports higher absolute growth rates, increased branching, greater pod formation, heavier seeds, and ultimately higher grain yield. The results align with the studies by Dzhidzalov *et al*. [30] and Shi *et al*. [31], which highlighted the direct relationship between photosynthesis and dry matter accumulation in soybeans. Additionally, research by Mete *et al*. [27] and AlGarni *et al*. [32] indicated that NPK application leads to a greater increase in soybean yield compared to organic matter application.

Table 1. Yield and yield contributing characters at different soil fertility conditions.

Treatments	Branch plant^{-1}	Pods plant^{-1}	Grain pod^{-1}	1000 grain weight	Grain yield (ton ha^{1})	% yield increase
F_0	3.78 ± 0.19^b	60.45 ± 1.68^c	7.89 ± 0.70^a	10.17 ± 0.31^b	1.18 ± 0.09^d	0.00
F_1	3.66 ± 0.18^b	60.40 ± 2.89^c	8.22 ± 0.51^a	10.07 ± 0.26^b	1.40 ± 0.11^c	18.64
F_2	4.11 ± 0.32^a	72.22 ± 2.50^a	8.22 ± 0.42^a	11.51 ± 0.87^a	2.33 ± 0.19^a	97.46
F_3	4.44 ± 0.31^a	66.22 ± 2.77^b	8.11 ± 0.51^a	10.83 ± 0.29^a	1.84 ± 0.05^b	55.93

This means having different letters are significantly different (Duncan's Multiple Range Test, $P < 0.05$)

These findings suggest that achieving a high growth rate during the flowering and vegetative phases is crucial for maximizing seed yield in soybeans. A crop's capacity to efficiently capture solar radiation early on and convert it into biomass plays a significant role in determining its overall growth and productivity [33]. In soybeans, enhanced light interception during the early seedling stages promotes rapid initial growth, ultimately leading to increased yields [11, 34]. The present study observed a similar trend, where NPK-treated soybeans exhibited greater absolute growth rate (AGR) and total dry mass (TDM) in the early growth stages, contributing to the highest seed yield.

Conclusion

In conclusion, the findings of this study demonstrate that NPK-treated soybeans exhibited the highest chlorophyll content, leading to the greatest absolute growth rate (AGR) and total dry mass (TDM) during the early growth and flowering stages. This, in turn, resulted in a higher number of seed weights, branches, and pods per plant, ultimately boosting seed yield. Thus, it can be noticed that increased chlorophyll content enhances the absolute growth rate and is strongly linked to higher seed yield.

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Conflict of Interest: None

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Ethics Statement: None

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