Effects of Fertilization on Soybean Productivity

Tazeen Fatima Khan[1], Ishrat Jahan Sanchary[2], Titu Najmur Rahman[3]

[1]Department of Soil, Water and Environment, University of Dhaka, Dhaka, Bangladesh
[2]Department of Soil and Environmental Sciences, University of Barishal, Bangladesh
[3]Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh

Abstract
Soybean is one of the potential oilseed crops in Bangladesh. The soybean production in our country is lower than other countries because of poor nutrient management. The yield of soybean can be increased by adopting proper fertilization plan. An experiment was conducted to assess the effects of phosphorus and potassium on soybean production (cv. Binasoybean-2). The experiment was consisted of five levels of phosphorus and potassium *viz.* 0, 20, 40, 80 and 100 kg/ ha as basal application. A randomized complete block design was followed with four replications. We observed maximum seed yield, tallest plant, highest chlorophyll content and highest weight of shoot and root biomasses in 80 kg/ ha of phosphorus and potassium. Both 40 kg/ha and 80 kg/ ha of phosphorus and potassium treatments significantly increased organic carbon and available forms of nitrogen, phosphorus and potassium contents in soil compared to the controls. However, fertilizer levels above 100 kg/ ha resulted in poor quality of seeds leading to a reduction in yield. The results suggest that phosphorus and potassium fertilization was beneficial in soybean production for enhancing both quality and quantity.

Keywords: Soybean, Fertilizer, Phosphorus, Potassium, Production.

Introduction

Soybean (*Glycine max*) is one of the most popular, native legume species in North America, Europe, East and central Asia, providing high yields and edible beans throughout a wide range of environmental conditions [1]. Soybean is the most common oilseed crop in Bangladesh as it is available to all classes of people. The climatic condition of Bangladesh favors its growth almost throughout the year. Significant amounts of dietary minerals, B vitamins and phytic acid are found in soybeans. Soy vegetable oil, product of processing the soybean crop, is extensively used in food and industrial applications. Being one of the most important protein sources, soybean is used for feeding the farm animals [2].

Soybean seed is rich in nutrients; together, protein and soybean oil content account for 56% of dry soybeans by weight (36% protein and 20% fat). The remainder consists of 30% carbohydrates, 9% water and 5% ash . Soybeans comprise approximately 8% seed coat or hull, 90% cotyledons and 2% hypocotyl axis or germ [3]. A 100-gram reference quantity of raw soybeans supplies 1,866 kilojoules (446 kilocalories) of food energy. Soybeans are a rich source of essential nutrients, providing in a 100-gram serving high contents of the Daily Value (DV) especially for protein (36% DV), dietary fiber (37%), iron (121%), manganese (120%), phosphorus (101%) and several B vitamins, including folate (94%). High contents also exist for K vitamin, magnesium, zinc and potassium [2, 3].

It was documented that the global in annual production of soybean is 365.79 million tons in an area of 130.90 million hectares. In Bangladesh, 96,921 tons of soybean is produced per year in 62,870 hectares of cultivated lands making up 1.54 tons/ha, which is much lower than the world average of 2.79 tons/ha [4, 5]. Bangladesh is facing acute shortage of edible oil for the past few years. the nation's ongoing edible oil shortage can be greatly alleviated by soybeans. Probable reasons for the low yield of soybean in Bangladesh can be poor fertilizer management and lack of high yielding varieties. Most farmers are not willing to deal with the soybean because of its low profit [6]. In Bangladesh, opportunities are available to increase both the area and productivity of soybean because of the availability of high yielding improved varieties and suitable agro-climatic conditions [4].

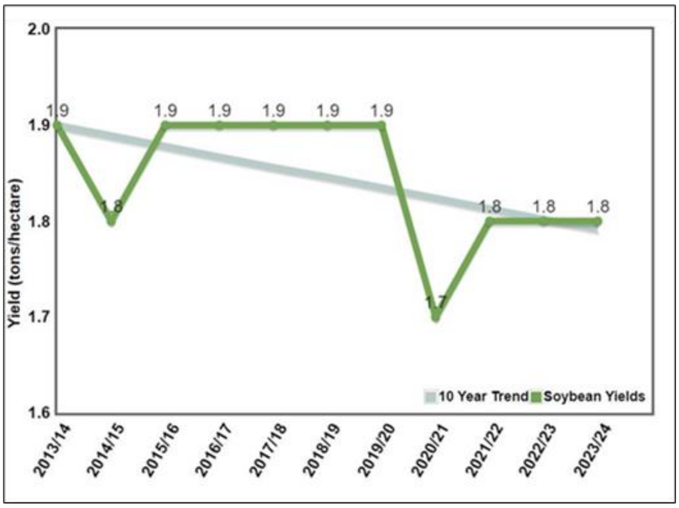

Figure 1. Ten Years Trend of Soybean Yield in Bangladesh [5]

Per acre production of soybean can be increased by adopting proper fertilization plan, particularly phosphorus and potassium. Both phosphorus and potassium are known as essential nutrients for soybean, and considered as the second and third major nutrients after nitrogen. Studies reported that [7] fertilizers not only improve the grain yield of soybean but also their superior nutritional and market quality. Phosphorus plays a critical role in cell division leading to the development of new plant tissue. Phosphorus acts as a part of the plant structural compounds (e.g. ATP, NADPH, nucleic acids, phospholipids, plasma membranes and sugar-phosphates) and also as a catalyst in the conversion of biochemical reactions in plants [8]. Phosphorus plays a vital role in capturing and converting the sun's energy into the useful plant compounds during the photosynthesis. Being an essential component of DNA and RNA, phosphorus determines the genetic code to build proteins and other compounds required for plant structure and genetic transfer [9]. Potassium helps to activate different enzymes by physically changing the shape of the enzyme molecule, releasing nutrients from the complex compounds for the microbes which ultimately enhance crop production [10, 11].

In the present study we hypothesized that due to the lack of optimum supply of phosphorus and potassium, the growth of soybean is hampered resulting in yield reduction. Severe deficiencies during seed formation have detrimental effects on yield quantity as well as reduction in nutrient contents of the soil [12]. The overarching aim of the present experiment was therefore to determine the effects of phosphorus and potassium fertilizers on the growth and yield of soybean.

Materials and methods

Field experiments were conducted in Mymensingh, Bangladesh. The sampling site was medium highland in AEZ-9 (Non-calcareous Dark Grey Soil). The soil was silty clay loam and acidic in reaction (5.8). The soil had a low organic matter content and fertility level is low to medium. There were different agricultural practices in various seasons. B. Aus, T. Aus, T. Aman and jute were grown during the summer whereas wheat, potato, tobacco, mustard and boro were found to grow in winter seasons [13].

Seeds of soybean (cv. Binasoybean-2) were collected from Bangladesh Agricultural Research Institute (BARI). We chose Binasoybean-2 as it was a short duration variety (90 – 105 days after planting) and expected yield was 2.4 – 3.3 tons/ ha [14]. The seeds (cv. Binasoybean-2) were sown in the month of November in 2-3 cm deep furrows. Five levels of phosphorus and potassium fertilizers (0, 20, 40, 80 and 100 kg/ ha) were used as treatments. The experiment followed a randomized complete block design with four replications (n = 4). The unit plot size was 5m × 5m. The plot was fertilized with 120 kg/ ha urea, 90 kg/ ha triple super phosphate (TSP), 80 kg/ ha murate of potash (MP), 5 kg/ ha zinc oxide, 2 kg/ ha soluble boron used as a source of nitrogen, phosphorus, potassium, zinc and boron respectively [13]. The whole amount of TSP, MP, soluble boron and half of urea were applied as basal dose. Seeds of soybean were sown with 1 kg seeds/ ha with 50 cm row to row and 30 cm plant to plant distance. The remaining urea was applied in two splits at 20 and 35 days after emergence. Four irrigations were made with tap water as per the requirement of crop. Weeding and mulching were also done [15]. The crop was kept under constant observations from sowing to harvesting. Soybean was harvested at 120 days when maximum pods were matured and turned to brown in color [16].

After harvesting, the plants were dried on the threshing floor 9-10 days. The winnowed seeds were dried in the sun for 5 days. The seeds of each plot were then recorded individually for further measurements. Five plants were randomly selected to determine plant height, chlorophyll content, root biomass and shoot biomass. Plant height was measured from the base to the tip of the highest fully expanded leaf using a ruler. For determining chlorophyll concentration, three measurements per leaf were done using an atLEAF CHL PLUS chlorophyll meter (Minolta, USA). Shoots of soybean were cut half a centimeter above the base of the soil and then weighed to determine the fresh weight of shoot biomass. Fresh roots were carefully collected from each plant and then washed thoroughly with deionised water on a 2 mm sieve to remove any excess soil. They were dried on a blue paper and fresh weight of root biomass was determined. Shoots and roots were then oven dried at 60 °C to determine dry weight of the shoot and root respectively [13].

Soils were also collected to measure the contents of soil organic carbon and available nitrogen, phosphorus as well as potassium in soil. Soil organic carbon was determined by Walkley and Black wet oxidation method [17]. Available nitrogen was determined by Kjeldahl method using NaOH and H_2SO_4 [17]. Available phosphorus was estimated by colorimetric method using a spectrophotometer (HACH DR 5000) at 880 nm [18]. Available potassium in the soil was estimated by a flame photometer [17, 18].

Collected data were analyzed using MINITAB (version 19) software. Data were tested for normal distribution using the Shapiro-Wilk and Kolmogorov-Smirnov test; and equal variance using Levene's mean test.

Results and discussion

Soybean took around 125 days to mature and at the end of the field experiment the plant were harvested. Growth parameters were significantly ($p \leq 0.05$) influenced by various levels of phosphorus and potassium fertilizers (Table 1). Seed yield varied from 1.96 to 3.62 t/ ha for phosphorus fertilizers and from 1.37 to 3.57 t/ ha for potassium fertilizers. Plant height varied significantly ($p \leq 0.05$) from 24.23 to 24.78 cm due to phosphorus fertilizers whereas plant height varied between 29.19 and 44.79 cm in responses to potassium fertilizers. Chlorophyll content varied significantly ($p \leq 0.05$) from 15.78 to 31.25 g/ m^2 and 16.24 to 39.84 g/ m^2 respectively. Likewise both fresh and dry weight of shoot and root biomass varied significantly ($p \leq 0.05$) due to the application of phosphorus and potassium fertilizers (Table 1). In responses to both phosphorus and potassium fertilizers growth parameters were highest for the plants grown with 80 kg/ ha fertilizers and the control plants produced the least. The yield advantage due to fertilization was at 80 kg/ ha was 72% and 98% for phosphorus and potassium respectively over the controls. The higher seed yield, increases in plant height and weight of the biomass due to the application of fertilizers might be due to the increased contents of assimilates produced during photosynthesis. Fertilizer could provide plant with nutrients that are needed for the metabolism and physiology of the plant. Another possible explanation of higher seed yield and increased plant height could be due to the increased activity of soil microbes due to the fertilizer application that could have broken down the complex soil organic matter into plant available forms. Our observation concurred with the observations of previous studies who noticed that fertilizers significantly influence on plant height and branching of soybean plant [17, 19]. However, the authors conducted the experiment with sulphur fertilizers. Significant influences of phosphorus and potassium on vegetative growth of oilseed crops (groundnut, sunflower and safflower) were also reported elsewhere [20, 21] who observed that pod formation and nodulation were increased noticeably when both potassium and phosphorus were applied together. Researchers [21, 22] documented that the soybean had nutrient deficiency symptoms *viz.,* chlorosis, necrosis, shortening of internodes and deformation without sulphur fertilization leading to decreased soybean production.

In addition, the soil might be deficient in phosphorus and potassium that would have contributed to the higher yield responses to added fertilizers. Fertilizers could enhance soil enzyme activity that could have facilitated mutual relationship between the soil microbes and plants leading to increased number of tillers and primary branches per plant [16, 19]. Addition of fertilizers (above 80 kg/ ha) tended to decrease seed yield and plant growth parameters (plant height, chlorophyll content, fresh and dry weight of shoot and root) in both cases of phosphorus and potassium (Table 1). The negative responses of higher doses of fertilizers might be due to plant stress making the plants susceptible to diseases and pest attacks [22]. Excess phosphorus and potassium fertilizers could burn or desiccate roots resulting from the effects of increasing phosphorus and potassium levels in soil without increase in other essential nutrients.

Table 1. Soybean Plant (cv. Binasoybean-2) Growth Parameters Influenced by Different Doses of Phosphorus and Potassium Fertilizers. Values Having the Same Letter(s) Do Not Differ Significantly Whereas Values with Different Letter(s) Differ Significantly.

Treatments (P levels kg/ ha)	Seed yield (t/ ha)	Plant height (cm)	Chlorophyll content (g/ m^2)	Fresh weight of shoot biomass	Dry weight of shoot biomass	Fresh weight of root biomass	Dry weight of root biomass

				(g)	(g)	(g)	(g)
0	1.96c	23.78b	15.78b	1.04c	0.78c	0.83c	0.64c
20	2.72b	28.98a	19.94ab	1.43b	0.97a	1.21a	1.04a
40	3.21a	35.73c	24.74a	1.98a	1.36b	1.26b	1.18b
80	3.62a	39.39d	31.25c	2.86d	1.87ac	1.74ab	1.59ab
100	2.05c	24.23b	16.43b	1.11c	0.81c	0.92c	0.78c
Treatments (K levels kg/ ha)							
0	1.94d	29.19c	16.24c	1.26b	0.82bc	0.98c	0.41c
20	2.34c	32.17b	20.73b	1.49a	1.07ab	1.53a	1.13a
40	2.93b	39.44a	24.14a	2.23c	1.88a	1.92b	1.61b
80	3.57a	44.79ab	39.84cb	2.94d	2.37d	2.46b	1.84b
100	1.37d	30.04c	17.64c	1.19b	0.96c	1.02c	0.72c

Plant parameters in the present study were significantly ($p \leq 0.05$) influenced by the interaction effect between phosphorus and potassium fertilizations (Table 2). The maximum seed yield (4.26 t/ ha) was observed for P100 × K80 which was significant to P100 × K20, P40 × K100, P40 × K40, P40 × K20, P20 × K100, P20 × K80. The tallest plant (49.03 cm) was recorded in P80 × K80 whereas the lowest plant (25.46 cm) was observed in P100 × K100 which had significant relationships with P100 × K20, P80 × K100, P40 × K100 and P0 × K0. The highest chlorophyll content (29.35 g/ m^2), fresh weight of shoot biomass (2.91 g) and dry weight of shoot biomass (1.12 g) was recoded in P80 × K80 treatment. Fresh weight of root biomass (1.77 g) and dry weight of root biomass (1.07 g) was observed in P20 × K80 treatment. The lowest seed yield and plant height were found with P0 × K0 and our findings were in line with other studies [16] [21] [22]. Previous studies mentioned lower growth of soybean without fertilization [21] [23]. However, the findings were largely dependent on local climatic conditions (temperature, precipitation, relative humidity, etc.), soil characteristics (pH, nutrient contents, texture, etc.,) and fertilizer types (organic/ inorganic) as mentioned by Imamul and Shamima [24].

Table 2. Interaction Effect of Different Levels of Phosphorus and Potassium Fertilizers on Growth Characters of Soybean (cv. Binasoybean-2). Values Having the Same Letter(s) Do Not Differ Significantly Whereas Values with Different Letter(s) Differ Significantly.

P treatment × K treatment	Seed yield (t/ ha)	Plant height (cm)	Chlorophyll content (g/ m^2)	Fresh weight of shoot biomass (g)	Dry weight of shoot biomass (g)	Fresh weight of root biomass (g)	Dry weight of root biomass (g)
P0 × K0	0.94b	25.74bc	14.58bc	1.32d	0.81d	0.83f	0.36g
P0 × K20	2.43c	29.27de	18.45d	1.65d	0.74de	0.67de	0.34gh
P0 × K40	3.34d	34.26de	20.34b	1.98e	0.52e	0.87de	0.75g
P0 × K80	3.89a	37.12e	23.97bc	2.46b	0.67d	0.60de	0.41f
P0 × K100	3.87cd	36.44d	22.79d	1.32c	0.63c	0.62de	0.43fg
P20 × K0	2.23c	26.25c	15.48b	1.11b	0.97bc	1.03bc	0.96f
P20 × K20	2.89a	28.14a	17.34a	1.43b	0.10a	0.43b	0.55cd

P20 × K40	3.16a	31.03de	21.46bc	1.87c	0.17c	1.19b	0.54bc
P20 × K80	3.67bc	34.82de	22.75e	2.13bc	0.26c	1.77g	1.07ef
P20 × K100	2.74bc	33.15b	21.01cd	2.16bc	0.93b	1.08b	0.44e
P40 × K0	1.78b	29.15c	17.96bc	1.03a	0.11c	0.80ef	0.32f
P40 × K20	2.56bc	30.35de	19.46bc	1.02c	0.12c	0.51cd	0.25f
P40 × K40	2.82bc	34.79de	22.43cd	0.71bc	0.36b	0.43a	0.36bc
P40 × K80	3.14b	38.03b	26.23cd	1.02ac	0.46c	0.74c	0.47bc
P40 × K100	1.79bc	24.37bc	25.26d	1.19c	0.72bc	0.71cd	0.63b
P80 × K0	1.36b	26.15b	18.34a	1.24a	0.76bc	0.64d	0.69b
P80 × K20	1.94c	28.58b	21.42c	1.28c	0.88de	0.98d	0.77g
P80 × K40	2.73d	35.86c	27.31b	2.09d	0.10de	1.29g	0.86a
P80 × K80	3.75d	49.03f	29.35ab	2.91de	1.12e	0.91a	0.51d
P80 × K100	3.07c	25.64bc	19.66bc	1.44d	0.92cd	0.73ef	0.54e
P100 × K0	2.57cd	27.36de	18.02d	1.65d	0.90d	0.77ef	0.26de
P100 × K20	3.64bc	25.16bc	22.86bd	2.45bc	0.18bc	0.64f	0.21ab
P100 × K40	3.91b	29.48de	26.53bc	1.13bc	1.08c	0.36de	0.07bc
P100 × K80	4.26bc	33.98de	29.04bc	1.19a	0.84cd	0.39e	0.05ab
P100 × K100	3.18c	25.46bc	28.77d	1.07ac	0.62cd	0.42de	0.04e

Phosphorus and potassium fertilizers showed highly significant ($p \leq 0.05$) influence on the soil organic carbon and available forms of nitrogen, phosphorus and potassium (Table 3). Contents of soil organic carbon ranged between 0.53% and 1.75% and the lowest being recorded for the control treatments. Contents of available nitrogen, phosphorus and potassium ranged between 34.81 and 59.86 mg/ kg, between 5.43 and 29.43 mg/kg, and between 30.89 and 64.44 mg/ kg respectively. For the available nitrogen, phosphorus and potassium the lowest being recorded for the control treatments (Table 3).

Increase in phosphorus levels increased contents of organic carbon, available nitrogen, phosphorus and potassium up to 40 kg/ ha followed by 80 kg/ ha and then tended to decrease in 100 kg/ ha. No significant difference ($p > 0.05$) was observed for organic carbon between 20 and 100 kg/ ha phosphorus and potassium levels. For the available nitrogen, there was no significant variation found between 20 and 100 kg/ ha phosphorus levels, and between 0 and 100 kg/ ha potassium levels. Contents of available phosphorus and potassium followed the pattern of available nitrogen. Studies by Imamul and Shamima [24] reported that the application of phosphorus and potassium along with balanced amount of sulphur fertilizers significantly increased oil and protein contents in soybean and linseed that could lead to higher concentrations of available nutrients in the soil. Compared to the control treatments, 80 kg/ ha phosphorus and 80 kg/ ha potassium significantly increased the protein contents to 58% and 37% respectively [19]. Plants grown without fertilizers consistently contain lower protein (approximately 10% less) in soybean seed [19, 23]. These studies supported our findings. Fertilization practices not only improves the soil structure and texture, but also enhances carbon and other essential nutrients leading to a sustainable crop production [25]. It was well documented that phosphorus and potassium fertilizer applications significantly change cation exchange capacity and moisture content of the soil conducive to better crop productivity. In contrast, fertilizers beyond a certain level showed reductions in soil organic matter and changes in soil pH resulting in alterations in soil microbial composition and decreases in the abundance of soil invertebrates [23, 25]. Fertilizers above a certain level could make the soil relatively hypertonic solution. When the nutrient concentration becomes too high the osmotic pressure outside the roots becomes greater than inside the roots and consequently the plants are not able to uptake water and nutrients [26].

Table 3. Contents of Soil Organic Carbon, Available Nitrogen, Phosphorus and Potassium After Application of Different Levels of Phosphorus and Potassium Fertilizers. Values Having the Same Letter(s) Do Not Differ Significantly Whereas Values with Different Letter(s) Differ Significantly.

Treatments (P levels kg/ ha)	Soil organic carbon (%)	Available N (mg/ kg)	Available P (mg/ kg)	Available K (mg/ kg)
0	0.53c	34.81d	5.43a	30.89a
20	0.93b	37.92c	6.32c	34.77b
40	0.95a	42.91a	17.11b	39.68c
80	1.58d	53.25b	29.43d	47.47d
100	0.96b	35.06c	6.87c	34.45b
Treatments (K levels kg/ ha)	Soil organic carbon (%)	Available N (mg/ kg)	Available P (mg/ kg)	Available K (mg/ kg)
0	0.55c	35.43d	5.74c	32.74a
20	0.97d	41.18b	7.78b	34.69b
40	1.24b	48.11c	12.56d	51.61c
80	1.75a	59.86a	16.82a	64.44d
100	1.25d	37.11d	6.94e	34.43ab

Conclusion

The application of phosphorus and potassium at the rate of 40 kg/ha and 80 kg/ ha for growing soybean significantly increased seed yield, plant height, chlorophyll content, shoot and root biomasses, oil content as well as protein content. In all cases growth parameters were higher compared to the controls (without fertilization). Nutrient contents in the soil were also higher in response to fertilizers. However, phosphorus and potassium fertilizations beyond a certain level (100 kg/ ha) can result in lower seed viability, possibly by increasing pathogen activity and causing the plant cells to become plasmolysed. Fertilizer applications are typically optimized to achieve optimal yield and this finding is especially significant for maintaining sustainable crop production.

References

1. Ehizogie J.F., James O.E., Sunday A.O., (2015). Growth and Yield Response of Soyabean (Glycine max Merr.) to Organic and Inorganic Fertilizer in Edo Rainforest of Nigeria. American Journal of Plant Sciences, 6, 3293-3297.
2. Falodun E.J., Osaigbovo A.U. Remison S.U., (2010). The Effect of Packaged Organic and Inorganic Fertilizer on the Growth and Yield of Soya Bean (Glycine max). African Journal of General Agriculture, 6, 1256-1263.

3. Espinoza L., (2001). Effect of Fertilizer on Grain Yield of Soya Bean. European Journal of Agronomy, 13, 212-221.
4. Islam K.S., Ali M.M., Shahrin S., Cheesman, S., Alam S.N., Krupnik, T.J., (2022). Simple and Effective Management Methods that Can Improve Soybean Production in Bangladesh. Cereal Systems Initiative for South Asia, Phase III (CSISA III), CIMMYT, Dhaka, Bangladesh.
5. Bangladesh Bureau of Staistics (BBS). Statistical Yearbook of Bangladesh. Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.
6. Heena N.P., Lone R., Sumaira R., Bisma N., Azra, N.K., (2021). Chemical Fertilizers and Their Impact on Soil Health. Microbiota and Biofertilizers, 2, 18-21.
7. Balezentiene L., Klimas E., (2009). Effect of Organic and Mineral Fertilizers and Land Management on Soil Enzyme Activities. Agronomy Research, 7, 191–197.
8. Carstensen A., Herdean A., Schmidt S.B., Sharma A., Spetea C., Pribil M., Husted S., (2018) The Impacts of Phosphorus Deficiency on the Photosynthetic Electron Transport Chain. Plant Physiology, 177, 271–284.
9. Burman U., Garg B.K., Kathju, S., (2009). Effect of Phosphorus Application on Clusterbean under Different Intensities of Water Stress. Journal of Plant Nutrition, 32, 668–680.
10. Aneja M.K., Shilpi S., Frank F., Susanne S., Werner H., Gunther B., Jean C.M., Michael S., (2006). Microbial Colonization of Beech and Spruce Litter: Influence of Decomposition Site and Plant Litter Species on the Diversity of Microbial Community. Microbial Ecology, 52, 127–135.
11. Sophia E.C., James A.B., Alicja A., Sally S., Crispin A.H., Angéla J., Michelle, L.C., (2021). Perennial Ryegrass Contains Gluten-Like Proteins That Could Contaminate Cereal Crops. Frontiers in Nutrition, 28, 130-142.
12. Bhat R.A., Shafiq R., Mehmood M.A., Dervash M.A., Mushtaq N., Bhat J.I.A., Dar, G.H., (2017). Current Status of Nutrient Load in Dal Lake of Kashmir Himalaya. Journal of Pharmacognosy and Phytotherapy, 6, 165–169.
13. Bangladesh Agricultural Research Council BARC (2005). Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council, Dhaka.
14. United Nations Development Programme UNDP., Food and Agriculture Organization FAO) (1988). Land Resources Appraisal of Bangladesh for Agricultural Development. Report No. 2, Agro-ecological Regions of Bangladesh, UNDP, FAO, 212-221.
15. Ilda D.M., Marije S., (2022). The Impacts of Soy Production on Multi-dimensional Well-being and Ecosystem Services: A Systematic Review. Journal of Cleaner Production, 335, 130182.
16. Shrabani D., Swapan K.P., Md R.R., Susmita R., Jamil F.F.U., Md, H.R., (2022). Growth and Yield Response of Soybean to Sulphur and Boron Application. Journal of Bangladesh Agricultural University, 20, 12–19.
17. Pais I., Jones J.B., (1997). The Handbook of Trace Elements. St. Luice Press, Boca Raton.
18. Tazeen F.K., Mark E.H., (2023). Polyethylene Microplastic Can Adsorb Phosphate but is Unlikely to Limit Its Availability in Soil. Heliyon, 10, 23179.
19. Farhad I.S.M., Islam, M.N., Hoque, S., Bhuiyan, M.S.I., (2010). Role of Potassium and Sulphur on the Growth, Yield and Oil Content of Soybean (*Glycine max* L.). Academic Journal of Plant Sciences, 3, 99-103.
20. Chivenge P., Vanlauwe B., Six J., (2011). Does the Combined Application of Organic and Mineral Nutrient Sources Influence Maize Productivity? A Meta-Analysis. Plant Soil, 342, 1–30.

21. Parry F.A., Chattoo M.A., Magray M., Ganie S.A., Dar Z.M., Masood A., (2016). Effect of Different Levels of Sulphur and Boron on Growth and Nodulation of Garden Pea (*Pisum sativum* L.). Legume Research, 39, 466-469.
22. Longkumer L.T., Singh A.K., Jamir Z., Kumar, M., (2017). Effect of Sulphur and Boron Nutrition on Yield and Quality of Soybean (*Glycine max* L.) Grown in an Acid Soil. Communications in Soil Science and Plant Analysis, 48, 1-21.
23. Singh D.K., Kumar P., Mishra N., Singh A.K., Singh, S.K., 2012). Interactive Effect of Cobalt, Boron and Molybdenum at Different Fertility Status on Physiological Efficiency of Nitrogen, Phosphorus and Sulfur in Grain of Pea (*Pisum sativum* L.). Environmental Ecology, 30, 277-280.
24. Imamul H., Shamima N., (2002). Effect of Sulphur Fertilization on Yield and Nutrient Uptake of Sunflower Crop in an Albaquept Soil. Pakistan Journal of Biological Sciences, 5, 533-540.
25. Gentile R., Vanlauwe, B., Chivenge P., Six J., (2008). Interactive Effects from Combining Fertilizer and Organic Residue Inputs on Nitrogen Transformations. Soil Biology and Biochemistry, 40, 2375-2384.
26. Serrano M.P., Frikha M., Corchero J., Mateos G.G., (2013). Influence of Feed Form and Source of Soybean Meal on Growth Performance, Nutrient Retention, and Digestive Organ Size of Broilers. Poultry Science, 92, 693-708.