EFFECT OF PHOSPHOROUS AND BORON ON THE GROWTH AND YIELD OF POTATO

HUMYRA SIDDIKA

DEPARTMENT OF SOIL SCIENCE

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA -1207

JUNE 2022

EFFECT OF PHOSPHOROUS AND BORON ON THE GROWTH AND YIELD OF POTATO

BY

HUMYRA SIDDIKA
REGISTRATION NO. 14-05825
Email: humyrasiddika1996@gmail.com
Phone Number: 01955498607

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka-1207
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
IN
SOIL SCIENCE
SEMESTER: JANUARY – JUNE, 2022

Approved By

Prof. Dr. Md. Asaduzzaman Khan **Supervisor** **Department of Soil Science,** **Sher-e-Bangla Agricultural University**	**Prof. Dr. Alok Kumar Paul** **Co-supervisor** **Department of Soil Science,** **Sher-e-Bangla Agricultural University**

Prof. Dr. Mohammad Saiful Islam Bhuiyan
Chairman
Examination Committee
Department of Soil Science
Sher-e-Bangla Agricultural University, Dhaka-1207

Department of Soil Science,
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207
PABX: 9110351 & 9144270-79

CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF PHOSPHOROUS AND BORON ON THE GROWTH AND YIELD OF POTATO"** submitted to the **Faculty of Agriculture,** Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in SOIL SCIENCE,** embodies the results of a piece of bona fide research work carried out by **HUMYRA SIDDIKA,** Registration No. **14-05825**, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma in any other institution.

I further certify that any help or sources of information received during this investigation have been duly acknowledged.

Dated:
Dhaka, Bangladesh

(Prof. Dr. Md. Asaduzzaman Khan)
Supervisor
Department of Soil Science,
Sher-e-Bangla Agricultural University,
Dhaka - 1207

Dedicated to

My

Beloved Parents

ACKNOWLEDGEMENTS

All thanks to Allah for his ever-present kindness and great mercy in providing me countenance on which to complete my research work and the thesis leading to the attainment of Master of Science.

I express my deep appreciation, a profound sense of gratitude, and heartfelt thanks to my ***supervisor Dr. Md. Asaduzzaman Khan****, Professor, Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka, for his subtle guidance, scholastic supervision, constructive criticism, and constant inspiration throughout the course and in preparing the thesis. I greatly thank him.*

I also express my gratitude to the ***co-supervisor, Dr. Alok Kumar Paul,*** *Professor, Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka, for his ongoing support, kind recommendations, constructive critiques, and invaluable guidance in carrying out the research work and preparing the thesis.*

I am grateful to my teachers at Sher-e-Bangla Agricultural University in Dhaka, Bangladesh, for their patience and guidance during my academic career and for their input on this thesis.

I express gratitude to my friends and all well-wishers for their assistance during experiments, active encouragement, and inspiration that led to completing this study.

I would like to thank my parents, ***Md. Mosharof Hossain*** *and* ***Suraya Akter****, as well as my husband,* ***Iqbal Mahmud,*** *for everything they have done, prayed for, blessed, and supported me to reach this stage in my education.*

Humyra Siddika

June, 2022

EFFECT OF PHOSPHOROUS AND BORON ON THE GROWTH AND YIELD OF POTATO

ABSTRACT

The experiment was carried out at the research field, Sher-e-Bangla Agricultural University, Dhaka-1207, from November 2021 to February 2022 to study the effect of phosphorous and boron on the growth and yield of potato (*Solanum tuberosum*). Three levels of phosphorous (P_0 = 0 kg P ha^{-1}, P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}) and three levels of boron (B_0 = 0 kg B ha^{-1}, B_1 = 2 kg B ha^{-1}, P_2 = 3 kg B ha^{-1}) were used for this study. The experiment was carried out using RCBD with nine treatment combinations and three replications. The data on growth and yield parameters of potato were recorded. Most of the parameters were significantly affected by different levels of P application. Generally, P_2 gave the best results and showed the highest tuber yield (30.47 t ha^{-1}), and marketable yield (26.63 t ha^{-1}). Most of the parameters were also significantly affected by boron treatments. The highest yield (28.92 t ha^{-1}), and highest marketable yield (25.3 t ha^{-1}) resulted from B_2 treatment. Considering the combined effect of P and B the maximum plant height (50.70 cm), number of stems (6.17), number of leaves hill^{-1} (109), number of tubers hill^{-1} (7.33), weight of tubers hill^{-1} (552.10 gm), weight of tubers plot^{-1} (13.57 kg), yield (33.99 t ha^{-1}), marketable yield (29.54 t ha^{-1}), tuber length (18.70 cm) and tuber width (16.13 cm) resulted from the P_2B_2 treatment combination. On the other hand, the minimum plant height (38.10 cm), number of stems hill^{-1} (3.17), number of leaves hill^{-1} (51.53), number of tubers hill^{-1}(4.17), weight of tubers hill^{-1} (181.33 gm), weight of tubers plot^{-1} (4.38 kg), yield (10.97 t ha^{-1}), lowest marketable yield (6.18 t ha^{-1}), tuber length (15cm), and tuber width (12.13 cm) were recorded from P_0B_0 (control) treatment combination. So, considering the aforementioned findings, P_2 treatment (40 kg P ha^{-1}) with B_2 treatment (3 kg B ha^{-1}) performed the best results for the growth and yield of potato.

LIST OF CONTENTS

Chapter	Title	Page No.

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PLATES

LIST OF ACCRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
B	Boron
Ca	Calcium
cm	Centimeter
CV	Coefficient of Variance
DAP	Days After Planting
et al.	And others
FAO	Food and Agriculture Organization
$hill^{-1}$	Per hill
i.e.	id est (L), that is
j.	Journal
K	Potassium
kg	Kilogram (s)
LSD	Least Significant Difference
mg	Milligram
M.S	Master of Science
N	Nitrogen
P	Phosphorus
RDF	Recommended Dose of Fertilizer
Res.	Research
SAU	Sher-e-Bangla Agricultural University
ton ha^{-1}	Ton per hectare
var.	Variety
viz	Namely
°C	Degree Celceous
%	Percentage
μg	Microgram

CHAPTER I

INTRODUCTION

INTRODUCTION

Potato (*Solanum tuberosum L.*) is a starchy tuber crop, belonging to the family Solanaceae, that has become an integral part of diets around the world. Originating in the central Andean area of South America (Keeps, 1979), potato is now one of the most important food crops in the world. It currently feeds over a billion people globally and is cultivated in more than 100 nations (Islam *et al.*, 2020). It can be cultivated on practically every continent and is one of the most nutritious and diversified crops in the world (Khurana and Rana, 2000). For optimal development and output, potatoes need temperatures of 18–20 °C and elevations of between 1500–4200 meters (B. Aloo, 2021). Potatoes grow best in cool climates when there is no chance of frost. (Tang *et al*., 2018). Potatoes may grow in a pH range of 5 to 6.5 which is deep, well-drained, and friable (Mugo *et al*., 2021).

Nutritionally, potatoes have been nourishing people around the world for centuries. This versatile food is a staple in many diets, providing essential nutrients and vitamins that are necessary for optimal health. A single potato can provide a significant portion of an individual's daily caloric needs and is packed with essential minerals such as potassium, phosphorus, manganese, magnesium, folate, vitamin C, and Vitamin B6 (Haynes *et al*., 2012).

On a global scale, Bangladesh has made its mark as a major potato producer and it is the seventh-largest potato-producing country in the world (FAOSTAT, 2020). The total area under the potato crop and total annual production in Bangladesh is 461,351 hectares and 9,606,000 metric tons, respectively (FAOSTAT, 2020). Potatoes have several culinary applications; they may be cooked, roasted, fried, dried, canned, or even used as starch. Potatoes are mostly used as vegetables in Bangladesh. It is one of the most widely consumed vegetables and its production and consumption have been steadily increasing over time. (MOA, 2021). Compared to other vegetables, it is accessible year-round at inexpensive rates. Potato is now seen as a viable alternative to more traditional food crops such as rice and wheat. This is especially pertinent because many countries in South Asia are experiencing rapid population growth and rising demand for food.

Potato is one of the most significant vegetable crops and a balanced diet comprising around 75 to 80 percent water, 16 to 20 percent carbs, 2.5 to 3.2% crude protein, 1.2 to 2.2% true protein, 0.8 to 1.2% mineral water, 0.1 to 0.2% crude fats, 0.6% crude fiber, and certain vitamins (Schoenemann, 1977). Being a carbohydrate-rich crop, potato can partially substitute rice, which is our main food item. Bangladesh has good potato-growing conditions. Potato cultivation and production have increased during the last several decades. With the growth of high-yielding verities, potato output in Bangladesh has expanded. Despite this expansion, yield per unit of land remains low in comparison to many other potato-producing countries because of improper fertilizer use, poor seed quality, and suboptimal management techniques. Available reports indicate that potato production in Bangladesh can be increased by improving cultural practices among which optimization of manure and fertilizer, planting time, spacing, and use of optimally sized seed are important which greatly influences the yield of potato (Divis and Barta, 2001). Because potatoes have a shallow and undeveloped root system relative to their output, substantial quantities of soil nutrients are needed to produce excellent commercial yields (Stark and Love, 2003; Perrenoud, 1983).

Phosphorus is a deficient nutrient element in Bangladesh soils. It is largely absorbed as the monovalent phosphate anion ($H_2PO_4^-$) and much more slowly as the divalent anion (HPO_4^{-2}). In plants, phosphorus serves as a structural component of macromolecular structures including nucleic acids (RNA and DNA) and the phospholipids that make up cell membranes. Compared to other vegetable crops, potatoes need more phosphorus because their immature root systems are unable to adequately mobilize insoluble phosphates from the soil. (Iwama K., 2008 and Rosen *et al*., 2014). Potato has a low P uptake efficiency due to its shallow root system. The majority of roots are found in the top 30 cm of the soil (Mikkelsen, 2014). Potatoes respond to P fertilization in soils that test low in P, however, P application has also been observed to boost tuber yields in soils that test very rich in P (Sanderson *et al.,* 2003). P deficiency decreases the CO_2 absorption capacity of leaf; resulting in an insufficient supply of phosphates, preventing the export of triose phosphate from the chloroplast, affecting the synthesis of sucrose (Mengel *et al.,* 2001); causing delayed growth of tubers (McCollum, 1978). P can affect the number of tubers and tuber size distribution. Increases in tuber set with P application have been found by Sanderson *et al.* (2003). Sharma and Arora (1987) also reported that Potato tuber yield is known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers, and the time at which maximum yield is obtained. They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. They also noted that excessive use of P fertilizers is usually associated with reduced tuber weight by hastening the maturation period and reducing tuber size. Applied P has been found to increase the yield of small and medium size tubers (Hanley *et al.,* 1965). Excess P can move through runoff and erosion and potentially affect the quality of surface waters. Therefore, understanding the need for P in potato production systems is important.

Boron is involved in carbohydrate metabolism and protein synthesis. This element is necessary for the metabolism of phenol, lignification, and the transfer of sugar. B deficiency resulted in negative consequences on crop output and quality. Even if no deficiency signs are visible on the leaves, B insufficiency may negatively impact yield. This phenomenon is known as "hidden hunger." (Sathya, Pitchai, and Indirani, 2009). Consequently, B insufficiency is often seen as an unanticipated foe of agricultural development. Potato is a highly B-responsive crop, with growth, production, and quality all being significantly impacted by B nutrition. (Hazra, 2012). It was proposed that boron might enhance the quality of fresh and lightly processed potatoes. (Ierna *et al*., 2017; Sarkar *et al.,* 2018; Singh *et al*., 2018). The use of boron in potatoes improves the proportion of big and medium-sized tubers while reducing the number of tiny tubers (Das and Jena, 1973). The omission of boron application in potatoes reduces the tuber yield and quality of potatoes significantly compared to the balanced use of fertilizers (Prasad *et al.,* 2014).

Limited research has been done on micronutrients and their application method on potatoes. The present study was carried out to determine the effects of varying quantities of phosphorous and boron on potato production with the following objectives in mind:

- To observe the effect of phosphorous and boron on the growth and yield of potato
- To find out the suitable dose of phosphorous and boron fertilizer on the higher growth and yield of potato

CHAPTER II
REVIEW OF LITERATURE

REVIEW OF LITERATURE

Potato is one of the oldest and most widely consumed food in the world. Potato has been an integral part of Bangladeshi cuisine for generations. Despite the vast amount of research done on potato crops over the globe, there is an unadequate information of data on the effect of phosphorous and boron on the growth and yield parameters of Diamant potatoes. This chapter provides a brief review of the literature relevant to the present study.

2.1 Effects of phosphorous on the growth and yield of potato

Gelaye *et al.* (2022) conducted a study which consisted of three levels of phosphorus (0, 34.5 and 69 kg P_2O_5 ha^{-1}) and four levels of potassium (0, 100, 200 and 300 kg K_2O ha^{-1}) in a factorial arrangement using RCBD with three replications. The result of the study showed that all phenological parameters were significantly affected by the main effects of phosphorus and potassium fertilizer rates but not by their interactions. Growth parameters (plant height), and yield components (marketable and total tuber yield); were significantly influenced by the interaction effects of phosphorus and potassium fertilizer rates. The highest marketable (48.32 t ha^{-1}) and total tuber yield (49.14 t ha^{-1}) were attained from treatments received 34.5 kg P_2O_5 ha^{-1} with 200 kg K_2O ha^{-1}. While, the longest plant height (84.80 cm) was recorded on a treatment received, 34.5 kg P_2O_5 ha^{-1} and 200 kg K_2O ha^{-1}. Likewise, application of 34.5 kg P_2O_5 ha^{-1} gave the highest leaf area index (6.86).

Qiu *et al.*, (2022) did a study with the chipping potato 'Atlantic' to see how the P fertilization rates affected the yield and quality of the tubers. The results of this study showed that 48.9 kg P ha^{-1} P still increased tuber yield significantly compared to the control, which used 12.2 kg P ha^{-1} P fertilizer. The external tuber quality was significantly better with 48.9 kg P ha^{-1} fertilizer P than with the control with 12.2 kg P ha^{-1} fertilizer P.

Sebnie *et al.* (2021) studied to observe the response of potato (*Solanum tuberosum* L.) to nitrogen and phosphorus fertilizers in Sekota and Lasta districts of Eastern Amhara, Ethiopia. The result of the study revealed that nitrogen and phosphorus had a significant effect on plant height, marketable, and total yield of potato at Kechin Abeba. However phosphorus did not show a significant effect on plant height and unmarketable yield in Sekota district of the Woleh irrigation command area. The highest yield 45.55 t/ha was obtained from the combined application of 138 N and 23 P_2O_5 in Lalibela 17.12 and 16.99 t/ ha were found from the application of 138 N with 46 P_2O_5 kg/ha and 138 N with 23 P2O5 kg/ha from Sekota district of Woleh irrigation command area respectively. The application of 138 kg/ha N with 23 kg/ha P_2O_5 is the appropriate rates for optimum productivity of potato at Lalibela (Kechin Abeba) and Sekota (Woleh) irrigation command areas and the same agro-ecology.

Setu and Mitiku (2020) carried out a field experiment to determine how potato production, yield components, tuber quality, and economic benefit responded to nitrogen and phosphorus fertilizer. The findings showed that the factors governing potato development, yield, and quality were unaffected by the interplay of nitrogen and phosphorus. However, nitrogen alone affected plant height, tuber number per plant, number of stems per hill, and marketable and total tuber yield, but not tuber quality parameters. The majority of the yield, yield components, and tuber quality parameters did not respond to phosphorus treatments.

Belachew B. (2016) experimented to study the effect of different Nitrogen (N) and Phosphorus (P) levels on the growth, yield, and quality of potato. Treatments consisted of four levels of N (0, 55, 110, and 165 kg N ha^{-1}) and four levels of P (0, 45, 90, and 135 kg P ha^{-1}). Results revealed that application of N and P fertilizers significantly influenced plant height, days to 50% flowering, main stem number, days to physiological maturity, total tuber number, total tuber yield, marketable tuber yield, average tuber weight, and tuber dry matter percentage. Based on the study, it was suggested that farmers can be more benefited from using 110 kg/ha of nitrogen in combination with 135 kg/ha of phosphorus.

N.A Misgina (2016) stated that growth parameters, yield, and yield components of potatoes responded positively to PK fertilizers either applied as sole or in combination. The average tuber weight, marketable, and total tuber yield were significantly affected by P and K fertilizer levels and their interaction. The highest tuber yield, average tuber weight, number of tubers per plant, and number of stems per hill were obtained from the application of a combined fertilizer at the rate of P: 89.7 Kg P_2O_5/ha and K: 100 Kg K_2O/ha.

An investigation was carried out by Zewide *et al.* (2016) to find out “Potato (*Solanum tuberosum L.*) Growth and Tuber Quality. Soil Nitrogen and Phosphorus Content as Affected by Different Rates of Nitrogen and Phosphorus at Masha District in Southwestern Ethiopia”. They stated that potato growth, tuber quality, tuber number, and available P content of the soil are affected by N and P application rates. The lower and medium N and P rates were favoring tuber quality while the higher N and P rates were favoring potato growth, TN, and available P content of the soil.

Qadri *et al.* (2015) conducted an experiment in the Vegetable Experimental Area, Institute of Horticultural Science, University of Agriculture, and Faisalabad during 2013-2014 to evaluate the effect of soil-applied phosphorus (DAP) and foliar application of nitrogenous fertilizer (urea) on growth, yield, and quality of potato. The experiment was comprised of four different treatments of phosphorus (DAP, 46% P) and nitrogen (urea, 46% N) including a control. Treatments were T0 (DAP 160 + Urea 300 kg $acre^{-1}$), T1 (DAP 160 + Urea 5 kg $acre^{-1}$), T2 (DAP 100 + Urea 6 kg $acre^{-1}$) and T3 (DAP 120 + Urea 8 kg $acre^{-1}$). The overall fertilizer efficacy regarding yield and quality was: T3 was given after 30 days of sowing with one-week intervals in five split doses. Results indicated that T3 > T2 > T1 > T0.

Öztürk et al., (2010) conducted a study to determine the effects of nitrogen (0, 120, and 240 kg N/ha) and phosphorus (0, 90, and 180 kg P_2O_5 ha/1) doses on some tuber quality traits of the potato cultivar Agria under the ecological conditions of Erzurum in the years 2005 and 2006. The effects of N levels were significant only on the protein content of tubers while the P levels only significantly affected the oil content of the crisps. No significant N × P interaction effects were found on any of the traits evaluated. Based on these results, it could be concluded that the potato crop should be fertilized with 120 kg/ha N and that phosphorus fertilizers should be added when soils are P deficient in the Erzurum region.

According to Zelalem *et al.* (2009), increasing phosphorus treatment (0, 20, 40, and 60 kg/ha) increases significant days to flowering, plant height, above-ground biomass, underground biomass, marketable tuber output, and marketable tuber number.

The normal function of plants might be disrupted by either an insufficient or an excessive quantity of nitrogen and phosphorus (Glass *et al*., 2002; Mahmud et al., 2003; Taghavi *et al.,* 2004; Montemurro *et al.,* 2007).

Powon *et al.* (2006) carried out a field study to enhance the growth and yield of potatoes (*Solanum tuberosum* L.) under different levels of phosphorus and farm yard manure for 2 seasons at NARC – Kitale and on-farm Psigirio in 2002 and 2003. The experimental design was a Randomized Complete Block (RCB), with three replications. Nine treatments of phosphorus rates (0, 52.2, and 100.4 kg ha/1 and farmyard manure 0, 10, and 20t ha/1) either singly or in combination were used. Data were recorded on tuber dry weight; shoot dry weight and total yield of potatoes. Phosphorus and FYM had a significant ($p < 0.05$) influence on tuber dry weight; shoot dry weight and total yield depending on the season and year. A combination of P at 100.4 kg ha^{-1} and FYM at 20t ha^{-1} resulted in an increase of 82% tuber dry weight and 62% fresh tuber yield compared to the control. Tuber number and shoot dry weight were also affected by the application of P and FYM. Potato yield can therefore be improved through the application of phosphorus and farm yard manure

Asseffa (2005) did a study to find out the response of two improved potato varieties to nitrogen and phosphorus application. It was observed that increasing nitrogen and phosphorous application rate significantly decreased the specific gravity and dry matter content of potato tuber.

Mulubrhan (2004) conducted a study at Haramaya University to observe, “The Effects of Nitrogen, Phosphorus, and Potassium Fertilization on the Yield and Yield Components of Potato (*Solanum tuberosum L.*)”. It was found that the application of Nitrogen and Phosphorus significantly increased, total and marketable tuber yield, and tuber numbers per unit area.

Sanderson *et al.* (2003) stated that Potatoes are responsive to P fertilization on soils testing low in P, but yield increases from applied P have also been found on soils testing very high in P. They also found that P can affect the number of tubers and tuber size distribution. Increases in tuber set with P application.

According to Atkinson *et al.*, (2003), Hopkins *et al*. (2014) and Nyiraneza *et al.* (2017) Phosphorous is important for vine development, tuber production, tuber bulking, and tuber starch synthesis.

Allison *et al.* (2001) did a study to find out the effects of soil and foliar- applied phosphorus fertilizers on the potato (*Solanum tuberosum L*.) crop. They saw an increase in the number of tubers in three of the 22 field tests. Fertilizer P had a significant effect on tuber number only at those sites where fertilizer P affected fresh weight yield and where Olsen-P was < 16. The total increase in tuber number (> 10) was not due to an increase of stems per plant but an increase of tubers per stem.

Jenkins and Ali (1999) showed that phosphate fertilizer's favorable impact on growth might be explained through increased early canopy development and radiation interception. The research reported here, increased field-grown crops and the impacts of phosphorus availability on progeny tuber numbers, a commonly acknowledged but rarely documented in the literature and considers the consequences for tuber size grading. Relatively large amounts of fertilizer Phosphorus are frequently applied to potato crops and economic responses occur where phosphorus is essential for numerous metabolic processes.

When nitrogen and phosphorus fertilizers have been applied, strong yield responses have been seen for a variety of crops in a variety of locales, showing that these soils have low levels of these nutrients. (Berga *et al.,* 1994a: Yohannes, 1994).

Biswas and Mukherjee (1993); Miller and Donahue (1995) and Tisdale *et al*. (1995) have reported that the use of P fertilizer becomes imperative because the concentration of P in many soils is very low and it is also liable to different chemicals reactions that make it unavailable to plants. Plants grown in sufficient Phosphorous soils were observed to establish excellent root systems, strong stems, mature early, and generate a high yield, but plants cultivated in P-deficient soils displayed stunted growth, a low shoot-to-root ratio, poor fruit and seed production, purpled colored leaves with a reddish color of the stem, and a purpled coloration of the stem. Phosphorous deficiency changes the way a plant works biochemically, such as by making it store more sucrose, reducing sugars, and sometimes starch (Rending and Taylor, 1989).

Sharma and Arora (1987) conducted a study on 'Effect of nitrogen, phosphorus and potassium application on yield of potato tubers (*Solanum tuberosum L.).*' They reported that Potato tuber yield is known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers, and the time at which maximum yield is obtained. They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. They observed that by accelerating maturity and lowering tuber size, high P fertilizer usage is often related to decreased tuber weight.

Sahota (1985) carried out an experiment to investigate the response of potato cv. Kufriojyoti to phosphorus and zinc interaction at Shillong, India applying a factorial combination of 0,26,52 or 78 kg P, and 0,15 or 30 kg Zn/ha. They reported that tuber yield was highest in the treatment at 78 kg P+ 30kg Zn/ha.

Christensen and Jackson (1981) studied to find out the potential for phosphorus toxicity in zinc-stressed corn and potato. They experimented with potatoes using three levels of zinc (0, 0.14, and 0.41 ppm) in factorial combination with 4 levels of phosphorus (0.02, 0.10, 1.0, and 3.0 ppm). It was found that potato plants responded to zinc only when the phosphorus supply was adequate.

Soltanpour and Cole (1978) did a study to observe, the ionic balance and growth of potatoes as affected by N plus P fertilization. They found that the application of N and P fertilizers increased leaf, stem, and tuber growth rates and, consequently yields. Fertilization also decreased the concentration of total cations and increased P in tubers.

Chaveri and Bornemisza (1977) experimented in the pacajas area in costarica to find out the effect of phosphorus and zinc on the growth and yield of potato cv. Atzimba. Four doses of phosphorus (0, 480, 720 and 960 kg P_2O_5/ha) were applied. They observed that total tuber yield increased significantly with the application of 480 kg P_2O_5/ha and a further increase in zinc. Nevertheless, the treatment of phosphorous and zinc at greater rates somewhat reduced yield.

Sommerfeld, T., and Knutson, K. (1965) carried out a study to find out the effects of nitrogen and phosphorus on the growth and development of Russet Burbank potatoes grown in southeastern Idaho. The study resulted that both N and P had direct effects on the growth and development of potatoes. Both affected the concentration of different elements in the plant tissue and tuber size. Reduced tuber size as a result of phosphorous was evident in both the field and greenhouse studies. Excess P delayed plant emergence; growth rate, primarily top growth, was increased by both N and P.

Hanley *et al.* (1965) found that applied P increase the yield of small and medium size tubers.

2.2 Effect of boron on growth and yield of potato

Rai *et al.* (2021) carried out an investigation on the "Effect of zinc and boron on the growth and yield of potato" at the Main Experiment Station, Vegetable Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP). There were seven treatment viz T1-control (RDF) NPK @ 150:100:120 kg/Ha T2- T1 +25 kg Zn soil /ha T3- T1 +5 kg Borax/ha, T4- T1 + 25 kg Zn SO4+5 kg Borax/ha. T5-T1+spray zinc (0.5%), T6-T1+ spray borax (0.5%), T7-T1 +spray zinc sulphate + borax @ 0.5%. The soil of the experimental field was silt loam in texture, having low organic carbon (0.35%) available N (145.5 kg/ha), P (15.7 kg/ha), K (255.0 kg/ha) and Zn (0.43 ppm), B (0.10

ppm). The potato variety Kufri neelkanth was sown. Nitrogen, phosphorous, potassium, zinc sulphate and borax were applied as per treatment. All the growth character yield and nutrient uptake (Zn and B) were found significantly superior in T4 treatment (where zinc sulphate and borax @ 25 and 5 kg/ha) over control (without zinc sulphate and borax). Maximum potato tuber yield (36.5 t/ha) and haulm yield (62.09 t/ha), zinc uptake (565.7 gm/ha), Boron uptake (620 gm/ha) and BC: ratio (3.44) was observed under T4 treatment. They concluded that application of N, P, K, zinc sulphate and Borax @ 150:100:120:25:5 kg/ha was found most suitable dose and combination for increasing yield, yield attribute character, nutrients availability and uptake (Zn and Boron), soil health and net return.

V. Shirur *et al.* (2021) experimented to study the effect of different levels of gypsum and boron on yield and nutrient content and uptake by potato with twelve treatments and replicated thrice using RCBD. The study revealed that a significantly higher number of tubers (4.78 plant^{-1}), tuber weight (536.12 g plant^{-1}), and tuber yield (28.91 t ha^{-1})was recorded with the application of 150 kg Gypsum ha^{-1} + Foliar spray of 0.5% Boron along with RDF +FYM. Significantly lower tuber yield was found in absolute control (12.08 t ha^{-1}). The nitrogen (1.65% and 1.64% respectively), phosphorus (0.29% and 0.46% respectively) and potassium(2.79% and 2.28% respectively) content in haulm and tuber increased significantly with T2 + 150 kg Gypsum ha^{-1} + Foliar spray of 0.5% Boron and was on par T6 (T2 + 150 kg Gypsum ha^{-1} + Soil application of Boron @ 5 kg ha^{-1}. Significantly lower nitrogen (1.22% and 1.02% respectively), phosphorus (0.20% and 0.24%) and potassium 1.36% and 1.48% respectively) content in haulm and tuber recorded in absolute control. As regards to uptake of nutrients significantly higher uptake of nitrogen, phosphorus and potassium by haulm and tuber was recorded due to the application of 150 kg Gypsum ha^{-1} + Foliar spray of 0.5 % Boron along with RDF + FYM. Significantly lower uptake of nitrogen, phosphorus, and potassium by haulm and tuber recorded in absolute control. The highest protein (10.28 %) and starch content (79.47%) in tubers was recorded in treatment T10 (RDF + 150 kg Gypsum ha^{-1} + Foliar spray of 0.5%) Boron over other treatments. The highest B: C ratio (4.51) was recorded in T10 over other treatments and the lowest B: C ratio was recorded in absolute control.

Lenka *et al.,* (2020) conducted a field experiment during the winter (rabi) seasons of 2015-16 and 2016-17 at Kalyani (Nadia), West Bengal, India, to determine the effect of boron and zinc on the growth and yield of potato (Solanum tuberosumL.) under lower Gangetic plains of West Bengal. They reported that the application of both zinc and boron improved the growth and yield of potato significantly. Zinc and boron acted synergistically in increasing the tuber yield. The highest total tuber yield (30.12 t/ha) of potato was recorded with foliar application of 0.1% boron + 0.1% zinc along with a recommended dose of fertilizer (RDF) of NPK. Soil application of only boron, only zinc and boron + zinc increased the total yield of tubers by 12.7%, 3.23% and 22.41%, respectively, over RDF of NPK only. The foliar application of only boron, only zinc and boron + zinc increased the total yield of tubers by 18.71%, 7.70% and 29.55%, respectively, over the RDF of NPK only. They also found that the effect of boron in increasing tuber yield of potatoes was more pronounced than zinc. Foliar application of B and Zn was found superior in increasing tuber yield to their soil application. The highest uptake of N, P, K, B and Zn were recorded with foliar application of B and Zn over RDF. Soil application of B and Zn significantly increased the B and Zn concentration in soil. Foliar application of Band Zn over RDF of NPK resulted in the highest net returns.

Magda A. Ewais *et al*. (2020) conducted two field experiments to study the effect of foliar application with different sources of potassium and three rates of boron as well as their interactions on tuber yield and quality (dry matter, starch, reducing sugar, total carbohydrates and specific gravity) of potato cultivar spunta. The obtained results showed that the high values of tubers number per plant, tubers weight/plant, total tuber yield and marketable tuber yield were recorded by the plants which sprayed with potassium sources compared to the control treatment. Also, the plants sprayed with 100 ppm boron gave the highest total tuber yield, average tuber weight and marketable tuber yield. Application of boron significantly increased the yield of large and medium-grade tubers and decrease proportionately small tubers. Mineral nutrients (N, P, K and B), total carbohydrates, specific gravity and starch content of tuber were significantly affected with foliar spraying with potassium sources than control treatment. In addition, the plants, which sprayed with potassium nitrate (KN) or potassium humate treatments were more effective than the rest treatments in enhancing the yield and yield components. Conclusively, from the obtained data in this study, it can be recommended foliar spraying with 1000ppm potassium sources to improve growth, number of tubers, yield per plant and total yield. Also, the combination of foliar spraying by potassium sources and 100ppm boron was highly beneficial in improving potato size, dry matter, average tuber weight, total yield and other quality parameters.

Muthanna *et al.,* (2017) experimented to study the effect of boron and sulphur application on plant morphology and yield of potato. Thirteen treatments were applied. Out of thirteen treatments one control, one recommended dose of fertilizers (N/P/K: 150/80/120 kg ha-1) and eleven treatment combinations along with a recommended dose of fertilizers (RDF) including 3 doses of boron (1 kg, 2 kg and 3 kg); 2 doses of sulphur (30 kg and 40 kg) and their combinations (1 kg boron + 30 kg sulphur, 2 kg boron + 30 kg sulphur, 3 kg boron + 30 kg sulphur, 1 kg boron + 40 kg sulphur, 2 kg boron + 40 kg sulphur and 3 kg boron + 40 kg sulphur) were applied. The study indicated that plant morphology and yield of potato plants were significantly influenced by boron and sulphur application. The maximum plant height and yield of marketable tubers (17.99 t/ha and 27.00 t/ha) were recorded in the plants treated with RDF + 2 kg B + 40 kg S during both years of investigation. They also found that RDF + 2 kg B + 40 kg S was statistically significant with the maximum values under characters viz., number of sprouts per tuber, stem diameter and number of marketable tubers/hill.

Peixoto *et al.* (1996) conducted an experiment to determine the response of potato cv. Desire to the application of boron fertilizer at four different concentrations (0, 1, 1.5, and 2 kg/ha) in Pakistan. In addition, NPK fertilizers and FYM (5t/ha) were applied as a base dressing to the crop. Compared to the control yield of 7.9 t/ha, the application of 2 kg B/ha increased the tuber yield to 10.9 t/ha.

Wijnholds (1996) conducted a study to investigate the effect of Nitro-Plus (12% N, 12% Ca, 3.2% B) on the yield of seed potatoes using row application of 2 levels of Nitro-Plus (200 and 250 L/ha). It was found that the treated crops grew more slowly in height and a large proportion of tubers exceeded 55 mm in diameter. However, the yield of marketable tubers was unaffected.

Sarkar *et al*. (1996) experimented with the Gangachara series of Mithapukur, Rangpur indicated that the highest tuber yield of 28.72 t/ha was produced by the combined effect of 150 kg N + 60 kg P +120 Kg K+ 20 kg S + 10 kg Zn + 2 kg B + 15 kg Mg +5t cow dung/ha.

Efkar, Jan, Khattak, and Khattak (1995) experimented to determine the response of potato cv. Desiree to the application of boron fertilizer at four levels (0, 1, 1.5, and 2 kg/ha) in Pakistan. The crop also got a 5-ton-per-hectare application of NPK and FYM. Compared to the control yield of 7.9 t/ha, the application of 1.5 kg B/ha increased tuber yield to 10.9 t/ha.

Kabir *et al.* (1994) reported that the application of boron with different levels showed a positive response to the yield of potatoes.

Lozer and Fecenko (1993) conducted a study in a small plot of loamy brown soil, and found that potatoes grew well when given foliar applications of 2 kg sodium humate and/or 0.5 kg Mn, 0.2 kg B, or both. Yield was increased by 4.2% with Sodium humate alone, 11.7-15.7% with Mn or B, and 17.8-23.6% with Sodium Humate + Mn and/or B. Tuber nitrate content was 45.5 mg/kg in the control and increased to 50.5 mg/ha with Mn alone and 47.2 mg with B alone. With the other treatments, it was reduced, and sodium humate + B had the lowest level (30.1 mg/kg).

Gupta and Sanderson (1993) performed a field investigation at two sites in the prince Eduard land using potatoes of the cv. Ellite III. They observed that whereas Ca and B treatments had no impact on tuber production, they did not influence the level of Ca in leaf tissue. The concentration of B in the leaf tissue in both samples was dramatically boosted by B application.

Pregno and Arour (1992) carried out a field experiment to find out boron deficiency and toxicity in potato cv. Sebago on an Oxisol of the Atherton Tablelands at North Queensland, Australia. It was found that tuber yield was the highest when 2 kg B/ha was applied followed by 4 kg/ha.

Quaggio and Ramos (1986) investigated the impact that boron has on the cultivation of potatoes. Boric acid was applied at the following rates: 0, 3, 6, 9, and 12 kg/ha to apply the boron. They concluded that the influence of boron on yield was more obvious on big-sized tubers than it was on smaller ones.

The effect of added trace element by Rasp (1985) in a year's crop rotation in which potatoes and cereals were grown on alternate years. It was noted that only boron tended to increase potato yield.

Tisdale *et al*. (1984) stated that Boron is required for plant growth processes like new development of meristematic tissue, translocation of sugar, starch nitrogen, and phosphorus, and synthesis of amino acids and proteins.

To determine the effectiveness of various applications of copper, zinc, and boron on the potato cultivar Kufrijyoti on acidic soil over the years 1986–1987 in Uttar Pradesh, India, Dwivedi and Dwivedi (1992) conducted an experiment. The results showed that basal dressings with boron produced the maximum yield.

Porter *et al.* (1986) conducted a field experiment to investigate the Katahdin potato variety's reaction to B treatment. The most effective method, according to their findings, was to provide boron as part of a complete fertilizer; however, when just 2.2 kg of boron per hectare was applied, tuber output remained unaffected, while 74.5 kg of boron per hectare caused plants to become stunted and lowered yield.

Palkovies and Gyori (1984) carried out a field experiment to investigate the influence that rusty brown forest soil has on the growth and yield of potato cv. Sonogy. Boron supplementation was revealed to be a factor in yield increases as well as an improvement in tuber quality, according to the findings.

Micronutrients are needed in comparatively lesser amounts for plant growth and development. Plant growth processes including the formation of new meristematic tissue, the movement of sugars, starches, nitrogen, and phosphorus, and the synthesis of amino acids and proteins all need boron (Tisdale *et al*, 1984).

Upadhayay and Grewal (1983) studied the impact of micronutrients via commercial combination on the growth and yield of cv. Chandramukhi. Trace elements including Zn, Cu, Mn, Mo, and B were shown to boost tuber output by increasing tuber size and number. The use of Zn and B considerably boosted tuber production with N, P, and K fertilizers on acidic brown hill soils in Sillong, India. (Sahota *et al.*1982).

Medevedev *et al.* (1981) discovered that using Zn, Mn, B, Cu, and Mo in the field with N, P, K compost and lime enhanced not only the tuber production but also the dry matter, starch, ash, protein, and carbohydrate content of tubers.

Omer & Hafez and Foda, (1982) stated that the boron at any concentration had little effect on plant and tuber number; but marketable tuber yield was increased with increasing concentration of boron.

Grewal and Trehan (1981) conducted an experiment to find out the effect of micronutrients on potatoes at different places in India and reported that potatoes gave yield response to the application of Zn and B at Gujrat and in the other places, tuber yield did not respond to the application of boron.

The response of potatoes to the application of Zn and B with NPK fertilizers was studied by Kirynkhin and Bezzubtseva (1980) on Derhopodzolic soil in the Moscow region. It was reported that zinc and boron increased 9-12.9% and 5-13% average tuber yield respectively over control. It was also found Zn and B increased dry matter, starch, protein, and ascorbic acid content of tubers.

Grewal and Trehan (1980) studied the effect of trace elements on potatoes. It was found that some cultivars showed a marked response to Zn and B application, while others showed little response.

Awasthi and Grewal (1977) studied potatoes on slightly acidic soils at Shilling, India using soil application of 25 kg $ZnSO_4$/ha or foliar application of o.1% boron solution. They observed that both Zn and B increased yield by 100-150 kg/ha.

The effect of mineral nutrients and growth regulators on growth and yield of potato cv. Kufrisundari was studied by Das and Padly (1976) who reported that spraying of 0.5% boron had a great influence on the yield and quality of potatoes.

Mica (1975) studied the influence of boron, manganese, and zinc on the yield and quality of potato cv. Karasara. It was found that the application of B and Mn increased the weight of both haulm and tubers.

According to Sapatyi and Shkvaruk (1973), the application of Zn, B, Co, and Ba was less effective in the growth, production, and quality of potatoes.

Gargantini *et al.* (1970) investigated the influence of NPK and numerous micronutrients in different combinations at the basal dressing on potato cv. Gunda and Feldsloha (1970). Boron uses enhanced potato output by 54% in Gunda and 28% in Feldsohn as compared to NPK alone. However, the addition of Fe, Zn, Cu, and Mn did not influence yield.

It is clear from the aforementioned research that phosphorous and boron have a major impact on potato production and yield components. However, there is a complete lack of information in the literature about the effects of zinc and boron on potato production in Bangladesh. In the current research, numerous combinations of nitrogen and phosphorus levels were taken to examine their impacts on vegetative growth, tuber production, and potato quality.

CHAPTER III
MATERIALS AND METHODS

MATERIALS AND METHODS

This chapter provides an overview of the experimental period, study location, experimental materials, treatments, experimental design, experimental methods, intercultural operations, data collecting, and statistical analysis. The details of experimental materials and methods are given below

3.1 Experimental period

The experiment was carried out during the period from November 2021 to February 2022.

3.2 Study location description

3.2.1 Geographical location

The experimental site was located at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207. It is 8.6 meters above sea level and situated at a latitude of $23^0$41' North and a longitude of $90^0$22' east. The trial field was medium-high land belonging to the Madhupur Tract, AEZ-28. The experimental site was shown in Appendix I. Evidence of the soil's fertility levels at the site of the experiment has been presented in Appendix IV.

3.2.2 Soil characteristics

The soil at the experimental location was similar to the general Soil Type of Shallow Red-Brown Terrace Soils under the Tejgaon series. Madhupur Tract typically has grey and mixed brown topsoil. The pH of the soil was 6.1, and its organic carbon content was 0.663 %. The chosen site was above flood level, and the testing period saw plenty of sunlight. The sites had accessible irrigation and drainage systems and were sufficiently level. The land was medium-high. The morphological, physical, and chemical characteristics of the initial soil are presented in Appendix IV and V.

3.2.3 Climate and weather

The experimental field was under subtropical climates with rainfall from April to September and scanty rainfall from October to March. The monthly means of daily maximum, minimum and average temperature, relative humidity, and total rainfall of the experimental site during the period between November 2021 to February 2022 have been presented in Appendix III.

3.3 Experimental details

3.3.1 Crop: Potato (***Solanum tuberosum L***)

3.3.2 Variety

The variety Diamant (BARI Alu-7) was developed by Bangladesh Agricultural Research Institute (BARI). The field duration from 85-90 days and the average yield from 25-30 t/ha.

3.3.3 Treatments and Factors of the experiment

The experiment included two different factors as treatments are as follows:

Factor A: Phosphorous

Level of Phosphorous: 3

- P_0 = 0 kg P/ha
- P_1 = 30kg P/ha
- P_2 = 40kg P/ha

Factor B: Boron

Level of Boron: 3

- B_0 = 0 kg B/ha
- B_1 = 2 kg B/ha
- B_2 = 3 kg B/ha

A total of nine combinations were applied with RDF (Recommended Dose of Fertilizer) under the existing study as follows: P_0B_0, P_0B_1, P_0B_2, P_1B_0, P_1B_1, P_1B_2, P_2B_0, P_2B_1, P_2B_2.

3.3.4: Experimental design and layout

The two-factor experiment was laid out in a Randomized Complete Block Design (RCBD) with 3 replications. The size of the unit plot was 2.5 m × 1.75 m. Plot-to-plot and block-to-block distances were 0.50m and 0.75 m, respectively. Treatments were randomly distributed within the blocks. The plots were raised to 10 cm. The total numbers of unit plot were 27. Appendix II displayed the layout of the experimental field.

3.3.5 Source of seed

The source of seed potato was Tuber Crop Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.4. Collection and processing of soil samples

Before the land preparation, soil samples of the experimental field's soil were taken from a depth of 0 to 15 cm from the surface. This was done using the composite sampling method. The collected soil was ground, put through a 2 mm sieve, and put in a clean, dry plastic container for physical and chemical analysis.

3.5 Crop management

3.5.1 Land preparation

The experimental land was prepared during the last week of October 2021. The land was ploughed and cross-ploughed four times, followed by laddering with a power tiller to achieve the desired tilt. Weeds and stubble were eliminated from the experimental area's corner by using spades. Finally, on November 15, 2021, five days before planting the seed tuber, the site was completely ready. To prevent flooding throughout the study period, a drainage system has been constructed around the site. The soil was treated with Furadan 5G @10 kg ha^{-1} when the plot was finally ploughed to protect the young seedlings from the attack of cutworms.

3.5.2 Manure and fertilizer application

The crop was fertilized as the Fertilizer Recommendation Guide (2018). Urea, MoP, TSP, zinc sulphate, gypsum, and boric acid were used as sources of nitrogen, potassium, phosphorus, zinc, sulphur, and boron, respectively. The recommended doses of N, K, S, Zn, and cowdung were 150, 150, 20, 4, and 10000 kg ha^{-1} respectively. Under the present study, TSP and boric acid were applied as per treatment. Cowdung was applied 10 days before the final land preparation. The total amount of zinc sulphate, MoP, gypsum, and half of the urea was applied at basal doses during final land preparation. The remaining 50% urea was side-dressed in two equal splits at 25 and 45 days after planting (DAP) during the first and second earthing up.

3.5.3 Seed preparation and sowing

The tubers were kept under diffuse light conditions to have healthy and good sprouts. Planting was done on 20 November 2021. The well-sprouted seed tubers were planted at a depth of 5-7 cm in furrows made 40 cm apart. Hill to hill distance was 15 cm. After planting, the seed tubers were covered with soil.

3.5.4 Intercultural operations

3.5.4.1 Weeding

The plant required regular weeding to prevent weed infestation. After all of the sprouts had come up, the weeds were carefully pulled out of the whole field. The first weeding was done on 4 December 2021. Another weeding was done on December 15, 2021, before applying the second top dressing of urea.

3.5.4.2 Irrigation

The frequency of irrigation was done based on the moisture status of the soil and the requirements of plants. Excess water was avoided, as it is harmful potato potato seedlings.

3.5.4.3 Earthing up

To maximize production and enhance the quality of the tubers by shielding them from the sun, the dirt was raised around the stems. During the growth stage, two earthing ups were performed. The first earthing up was done on December 15, 25 days after planting, while the second earthing up was done 20 days following the first earthing up.

3.5.4.4 Plant protection

Furadan 5G @ 10 kg ha^{-1} was applied in the soil at the time of final land preparation to control the cutworm. Confidor 70WG @100 gm ha^{-1} and Admire 200SL @ 500 ml ha^{-1} for controlling aphid and jassid that causes potato leaf curl. For the management of late blight of potatoes under wet and foggy conditions, Secure 600WG at 1kg/ha was administered every seven days.

3.5.4.5 Observation

Frequent field inspections were conducted to detect any changes in plants, pests, or disease infestation, and appropriate measures were implemented to ensure normal plant development.

3.5.5 Haulm cutting

Haulm cutting was done 7 days before harvesting when about 40–50% of plants showed signs of senescence and tops began to dry. After haulm cutting the tubers were kept under the soil for skin hardening. This was done to prevent damage to the tubers during harvesting and grading. Haulms were pulled manually.

3.5.6 Harvesting

Exactly seven days after the haulm was cut, on the 18th of February in 2022, the potatoes were harvested. Potatoes from each treatment were separately collected, sorted, bagged, labeled, and taken to the lab.

3.6 Collection of data

To assess the effect of phosphorous and boron rates on potato growth, and yield, data were recorded on the following parameters from the sample plants during the experiment:

A. Growth parameters

i. Plant height (cm)
ii. Number of stems hill^{-1}
iii. Number of leaves hill^{-1}

B. Yield and yield contributing parameters

i. Number of tubers hill^{-1}
ii. Average weight of tubers hill^{-1} (gm)
iii. Weight of tubers plot^{-1} (kg)
iv. Yield of tuber hectare^{-1} (t ha^{-1})
v. Marketable yield hectare^{-1}
vi. Size of tubers (cm)

C. Postharvest soil analysis

i. Particle size analysis
ii. Soil pH
iii. Organic carbon (%)
iv. Organic matter (%)
v. Available phosphorous (ppm)
vi. Available sulphur (ppm)

The procedure for recording data:

A summary of how the data was recorded during the study is stated below:

A. Growth parameters

i. Plant height (cm)

Plant height was taken to be the length between the bases of the plant to the apex at 30 DAP and 60 DAP. The height of 10 plants of each plot was measured in cm with the help of a meter scale and the average height was calculated.

ii. Number of stems hill^{-1}

The number of stems hill^{-1} that were counted during flowering, on average, five hills plot^{-1} were counted. Only stems arising from the mother tuber were considered as main stems (Zelalem *et al.*, 2009)

iii. Number of leaves hill^{-1}

The number of leaves hill^{-1} was counted on different days after sowing of crop duration. Leaves number hill^{-1} was recorded from pre-selected 5 hills by counting all leaves from each plot and the mean was calculated. Data was taken at 30 and 60 days after planting (DAP).

B. Yield parameter

i. Number of tubers hill^{-1}

The number of tubers from 5 hills was counted at harvest and an average number of tubers was calculated from each unit plot.

ii. Weight of tubers hill^{-1} (gm)

The weight of tubers from 10 selected hills was recorded and the average weight of tubers per hill was calculated from each unit plot.

iii. Weight of tubers plot^{-1} (kg)

The weight of tubers plot^{-1} was recorded at the time of harvest of all tubers from all plants of a plot.

iv. Tuber yield (t ha^{-1})

Tuber yield (t ha^{-1}) was calculated from that of per plot yield and expressed in ton per hectare (t ha^{-1}).

5. Marketable yield (t ha^{-1})

The tubers were collected from each plot and graded according to their suitability for sale; the remaining tubers were tallied and chosen as marketable yield and stated as ton per hectare (t ha^{-1}).

6. Sizes of potato (cm)

10 potatoes were chosen at random from each plot, and their length and breadth were measured with measuring tape and expressed in centimeters.

C. Post-harvest soil sampling and analysis

After the harvest of the crop, soil samples were collected from each plot at a depth of 0 to 15 cm. Soil samples of each plot were air-dried, crushed, and passed through a two mm (10 meshes) sieve. The soil samples were kept in a plastic container to determine the physical and chemical properties of the soil. Soil samples were analyzed for both physical and chemical characteristics viz. soil texture, soil pH, organic matter, available S, and available P contents.

The soil samples were analyzed by the following standard methods:

1. Particle size analysis of soil

The Hydrometer method was used for particle size analysis of the soil (Bouyoucos, 1927). The textural class was determined using Marshell's Triangular coordinate as designated by USDA (1951).

2. Soil pH

The pH of the soil was determined with the help of a glass electrode pH meter using a soil: water ratio being 1:2.5 (Jackson, 1973).

3. Organic matter

Wet oxidation was used to determine organic carbon in soil samples. (Page *et al*., 1982). The organic matter was oxidized using the underlying principle with an excess of 1N $K_2Cr_2O_7$ in the presence of conc. H_2SO_4 and conc. H_3PO_4 and the excess $K_2Cr_2O_7$ solution were titrated with 1N $FeSO_4$.

The percentage of organic carbon is determined from the following:

$$\% \text{ Organic carbon} = \frac{(B\text{-}T) \times N}{w} \times 0.003 \times 1.3 \times 100$$

Where, B = $FeSO_4.7H_2O$ required in blank titration

T = $FeSO_4.7H_2O$ required in actual titration

N = Strength of $FeSO_4.7H_2O$ solution

W = weight of soil taken

1.3 = conventional recovery factor

Soil organic matter content was calculated by multiplying the percent value of organic carbon with the Ven Bemmelen factor, 1.724 as described by Piper (1942). % organic matter = % organic carbon × 1.724.

4. Available phosphorus (ppm)

The soil's available P was evaluated using the ascorbic acid blue color technique. Available phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5 (Olsen *et al*., 1954). Phosphorus in the extract was then determined by developing blue color with a reduction of phospho-molybdate complex and the color intensity was measured colorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al*., 1982).

5. Available sulphur (ppm)

Available S in soil was determined by extracting the soil samples with 0.15% $CaCl_2$ solution (Page *et al*., 1982). The S content in the extract was determined turbidity metrically and the intensity of turbid was measured by spectrophotometer at 420 nm wavelength.

3.7 Statistical analysis

The collected data on different growth, yield, and quality parameters were subjected to analysis of variance (ANOVA) by using Statistix 10 computer program. All pairs of treatment means were compared using the Least Significant Difference (LSD) test at a 5% level of significance. The raw data management was completed by using a Microsoft Excel spreadsheet. (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The present investigation was overseen in the field to observe potato growth and yield as impacted by phosphorus and boron levels. This section shows various figures, tables, and appendices to display, analyze, and compare the data acquired from this research. The results with and all feasible explanations were given under the following headings

4.1 Growth parameters

4.1.1 Plant height (cm)

Effect of phosphorous on plant height of potato

Significant variation was observed in plant height at different growth stages of plants as influenced by the application of different phosphorous levels (Fig. 1 and Appendix VI). The upper limit of plant height (36.19 cm and 49.08 cm at 30 and 60 DAP respectively) was retained by P_2 treatment (40 kg P ha^{-1}). The lower limit of plant height (28.09 cm and 41.64 cm at 30 DAP and 60 DAP respectively) was retained by P_0 (0 kg P ha^{-1}). A similar experiment conducted by Firew *et al.* (2016) in eastern Ethiopia confirms that the application of Phosphorous increased the height of potato.

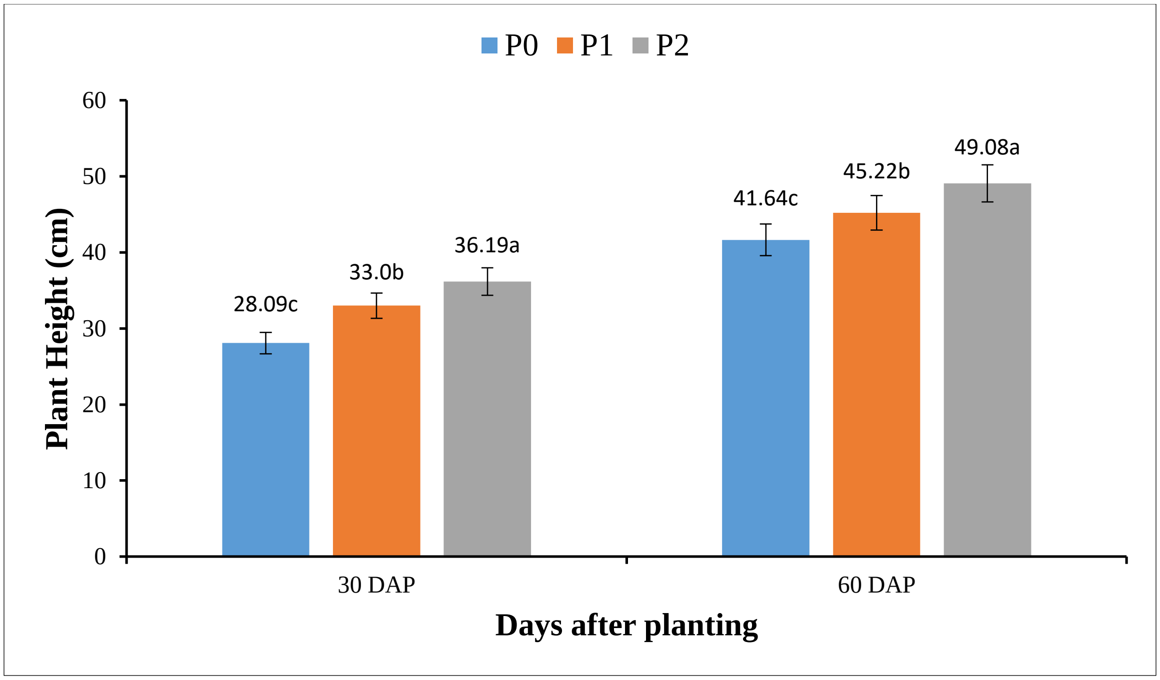


Fig.1. Effect of phosphorous on plant height of potato

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

Effect of boron on plant height of potato

Significant variation was detected in plant height at different growth stages as a result of the application of varying boron concentrations. (Fig. 2 and Appendix VI). At 30 DAP the upper limit of plant height (34.70 cm) was obtained by B_2 (3 kg B ha^{-1}), and the lower limit of plant height (29.39 cm) was found by B_0 (0 kg B ha^{-1}). Application of different B levels of the plant height at 60 DAP was observed to have outstanding distinction. The taller plant (47.16 cm) was observed from B_2 (3 kg B ha^{-1}) treatment and the shorter (43.44 cm) was in treatment B_0 (0 kg B ha^{-1}).

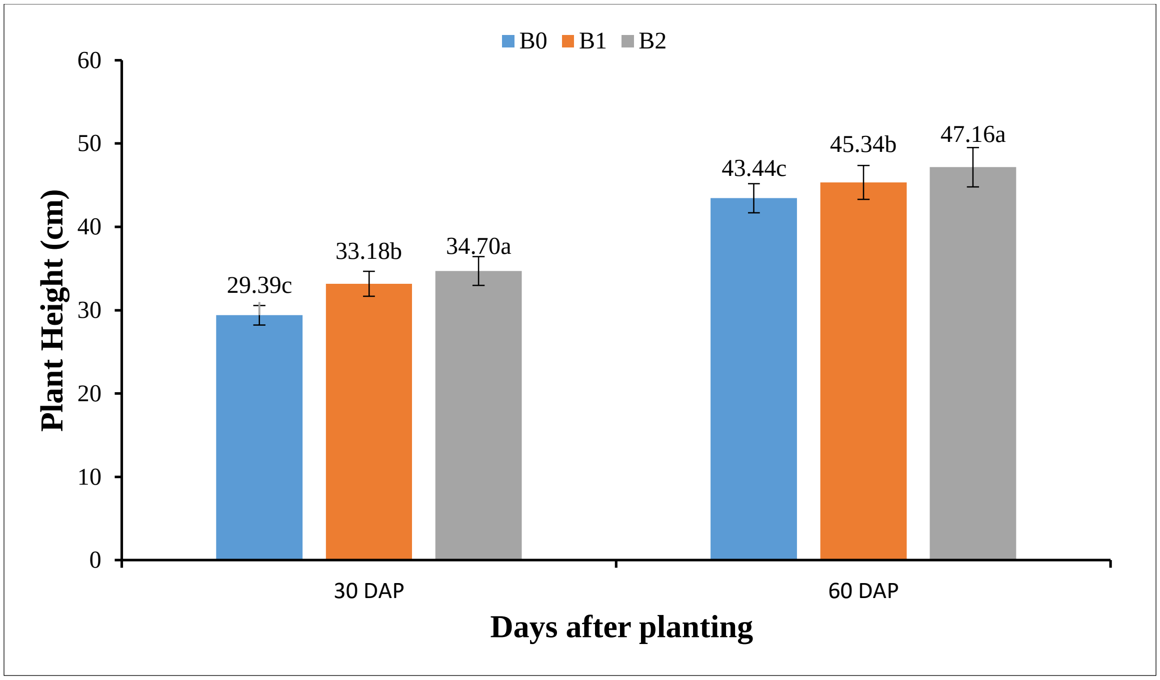


Fig.2. Effect of boron on plant height of potato

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on plant height of potato

In case of plant height at 30 and 60 DAP, the interaction effect of P and B levels was appeared statistically significant (Table 1. and Appendix VI). The maximum plant height (37.47 cm and 50.7 cm at 30 and 60 DAP respectively) was recorded at P_2B_2 treatment combination (40 kg P ha^{-1} and 3 kg B ha^{-1}). Minimum plant height (21.5 cm and 38.1 cm at 30 and 60 DAP respectively) was measured for the P_0B_0 (0 kg B ha^{-1} and 0 kg B ha^{-1}) treatment combination.

Table 1. The combined effect of phosphorous and boron on plant height of potato

Treatments	Plant Height (cm)	
	30 DAP	60 DAP
P_0B_0	21.5f	38.1g
P_0B_1	30.3e	42.37f
P_0B_2	32.5d	44.47e
P_1B_0	32.2d	44.43e
P_1B_1	32.17d	44.93e
P_1B_2	34.14c	46.30d
P_2B_0	34.53c	47.80c
P_2B_1	36.58b	48.73b
P_2B_2	37.47a	50.7a
$LSD_{0.05}$	0.53	0.54
CV (%)	1.0	0.7

In a column means having similar letter(s) are statistically identical and those having a dissimilar letter(s) differ significantly as per 0.05 level of probability

CV = Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

4.1.2 Number of leaves hill^{-1}

Effect of phosphorous on the number of leaves hill^{-1} of potato

The number of leaves hill^{-1} were significantly affected at various potato development stages with the application of variable phosphorus (P) levels. (Figure 5. and Appendix VIII). Results indicated that the treatment P_2 (40 kg P ha^{-1}) produced the highest number of leaves hill^{-1} (26.0 and 90.4 at 30 and 60 DAP, respectively) which was significantly different from all other treatments. The control treatment P_0 (0 kg P ha^{-1}) resulted in the lowest leaves hill^{-1} (18.2 and 60.5 at 30 and 60 DAP, respectively) which was also significantly different from all other treatments.

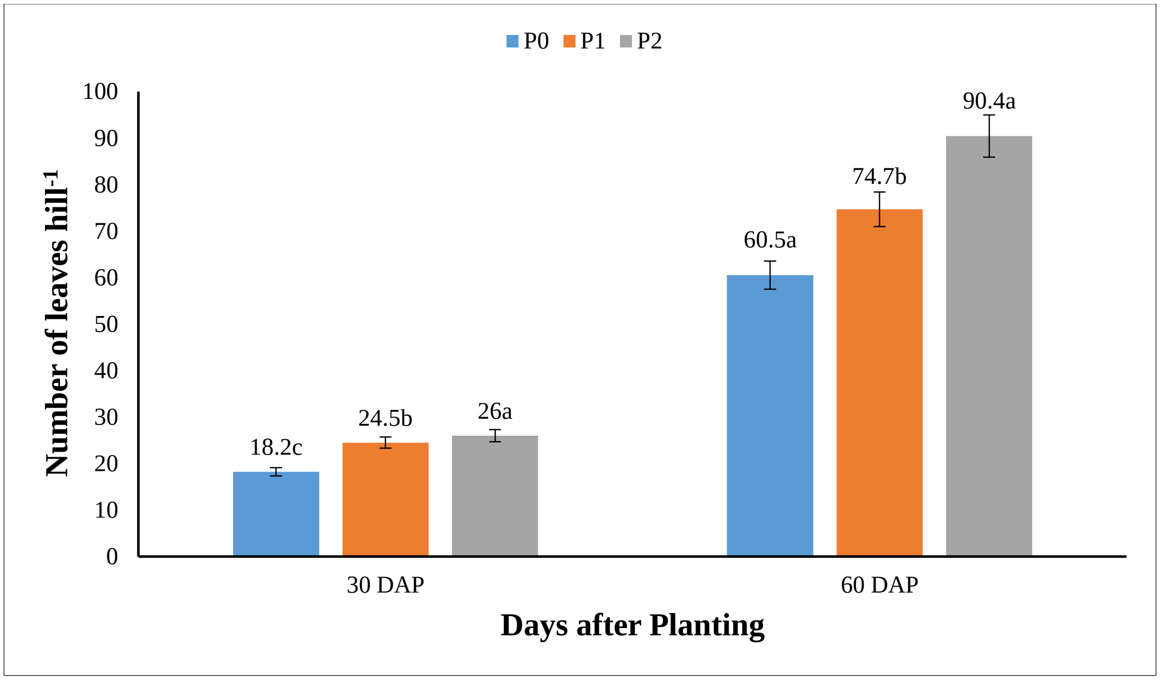


Fig. 3. Effect of phosphorous on the number of leaves hill^{-1} of potato

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the number of leaves hill^{-1} of potato

Boron (B) levels at various phases of development significantly impacted leaf production hill^{-1} (Figure 6. and Appendix VIII). The maximum number of leaves hill^{-1} (26.42 and 88.16 at 30 DAP and 60 DAP respectively) was achieved from treatment B_2 (3 kg B ha^{-1}) which was significantly different from all other treatments. The lowest number of leaves hill^{-1} (18.6 and 63.22 at 30 DAP and 60 DAP respectively) was obtained from the control treatment B_0 (0 kg B ha^{-1})

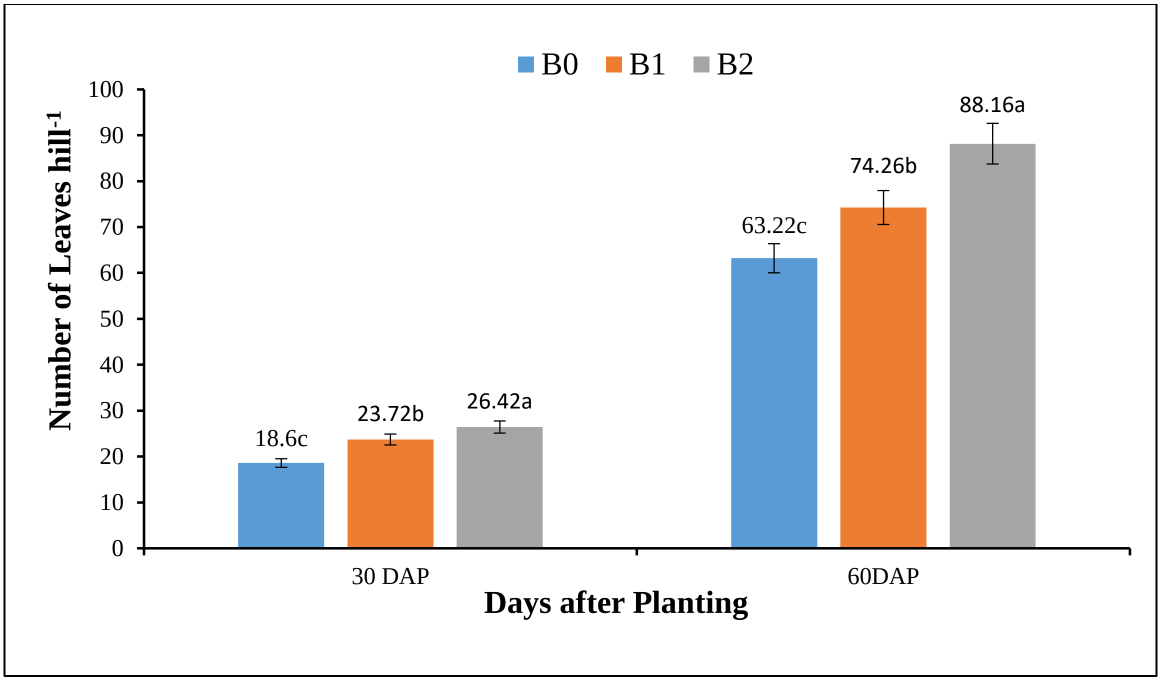


Fig. 4. Effect of Boron on the number of leaves hill^{-1} of potato

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined Effect of phosphorous and boron on the number of leaves hill^{-1} of potato

The combined impact of different P and B levels at various development stages significantly influenced the number of leaves hill^{-1} (Table 2 and Appendix VIII). At 30 DAP the highest number of leaves hill^{-1} (28.9) was recorded from the treatment combination of P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) which was statistically identical with P_1B_2 (30 kg P ha^{-1} and 3 kg B ha^{-1}). Treatment P_2B_1 produced maximum leaves (109.0) at 60 DAP which was significantly differ from other treatments. The treatment combination of P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) resulted in the lowest number of leaves hill^{-1} (13.40 and 51.53 at 30 and 60 DAP, respectively).

Table 2. The combined Effect of phosphorous and boron on the number of leaves hill^{-1} of potato

Treatments	Number of leaves hill^{-1}	
	30 DAP	60DAP
P_0B_0	13.4g	51.53e
P_0B_1	19.5f	61.7d
P_0B_2	21.7e	68.3cd
P_1B_0	19.5f	67.53cd
P_1B_1	25.47c	69.4cd
P_1B_2	28.57a	87.17b
P_2B_0	22.87d	70.60c
P_2B_1	26.2b	91.67b
P_2B_2	28.9a	109.0a
$LSD_{0.05}$	0.72	8.61
CV (%)	1.81	6.62

In a column means having similar letter(s) are statistically identical and those having a dissimilar letter(s) differ significantly as per 0.05 level of probability

CV = Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

4.1.3 Number of stems hill^{-1}

Effect of phosphorous on the number of stems hill^{-1} of potato

The recorded data on the number of stems hill^{-1} at different growth stages was affected significantly with the application of different P levels (Figure 3. and Appendix VII.). Results revealed that increasing application of phosphorous increased stem number hill^{-1}. The maximum stem number hill^{-1} (4.51 and 5.22 at 30 and 60 DAP respectively) was recorded from the treatment P_2 (40 kg P ha^{-1}) which was statistically different from other treatments. The lowest stem number hill^{-1} (3.24 and 4.01 at 30 and 60 DAP respectively) was obtained from the control treatment P_0 (0 kg P ha^{-1}). The result obtained from the present study was similar to the findings of Gray and Hughes, 1978; they observed that phosphorous influences haulm development and tuber quantity per plant, and high stem number per plant supported high tuber yield.

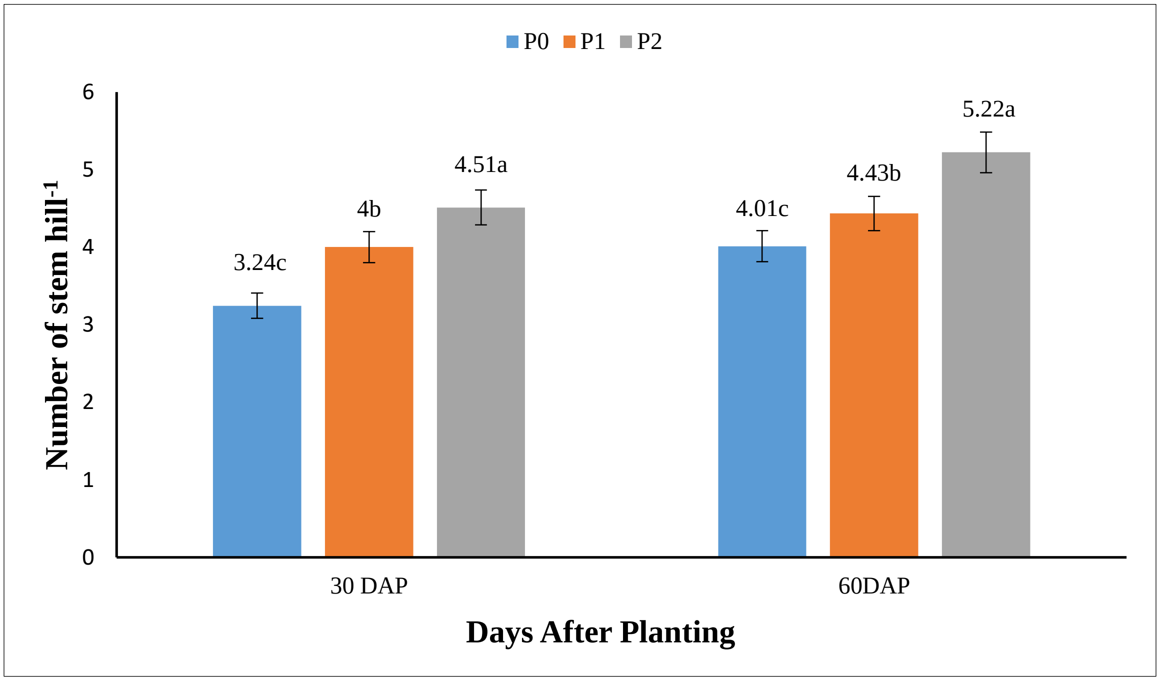


Fig. 5. Effect of phosphorous on the number of stem hill^{-1} of potato

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of Boron on the number of stem hill^{-1} of potato

Similar to Phosphorous, increasing the level of Boron significantly increased the stem number hill^{-1} of potato (Figure 4. And Appendix VII). The maximum stem number hill^{-1} (4.60 and 5.32 at 30 DAP and 60 DAP respectively) was recorded at B_2 (3 kg B ha^{-1}). The minimum stem number was (3.29 and 3.73c at 30DAP and 60 DAP respectively) obtained from the control B_0 (0 kg ha^{-1}). Maier *et al.* (2002) have also reported a significant increase in stem number plant^{-1} with boron fertilization in a greenhouse study which might be related to the fact that an adequate amount of boron forms a good root system, strong stem, and good growth.

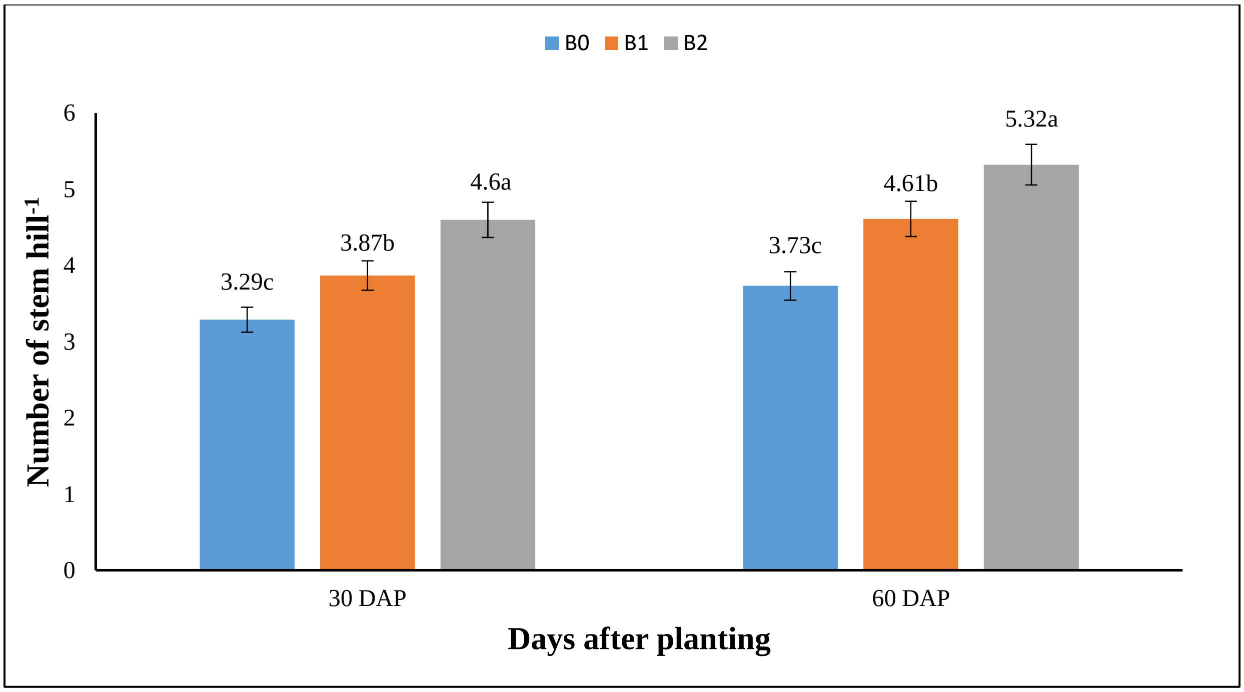


Fig. 6. Effect of boron on the number of stem hill^{-1} of potato

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the stem hill^{-1} of potato

The number of stems hill^{-1} was significantly influenced by the combined effect of different P and B levels at different growth stages (Table 3. and Appendix VII). The highest number of stems hill^{-1} (5 and 6.17 at 30 and 60 DAP respectively) was recorded from the treatment combination of P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) which was statistically different from other treatments. The lowest number of stems were (2.47 and 3.17 at 30 and 60 DAP respectively) obtained from the control treatment combination P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) which was also statistically different from other treatments.

Table 3. **The combined effect of phosphorous and boron on the number of stems hill^{-1}**

Treatments	Number of stems hill^{-1}	
	30 DAP	60 DAP
P_0B_0	2.47g	3.17g
P_0B_1	2.90f	4.17e
P_0B_2	4.37bc	4.70c
P_1B_0	3.47e	3.73f
P_1B_1	4.10cd	4.47cd
P_1B_2	4.43b	5.10b
P_2B_0	3.93d	4.30de
P_2B_1	4.60b	5.20b
P_2B_2	5.00a	6.17a
$LSD_{0.05}$	0.32	0.3
CV (%)	4.73	3.28

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

CV = Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1= 2 kg B ha^{-1}, B_2= 3 kg B ha^{-1}

4.2 Yield parameters and yield of potato

4.2.1 Number of tubers hill^{-1}

Effect of phosphorous on the numbers of tubers hill^{-1}

The collected data on the number of tubers hill^{-1} showed significant differences with the application of different Phosphorous levels (Figure 7. and Appendix IX). The highest tuber number was 6.94 resulting from P_2 treatment (40 kg P ha^{-1}) which was statistically different from other treatments. The lowest tuber number was 5.27 obtained from the control treatment P_0 (0 kg P ha^{-1}). According to Sommerfeld and Knutson (1965) and Sparrow *et al.* (1992), the application of phosphorus enhanced the number of potato tubers set per unit, suggesting that phosphorus has a function in aiding fast cell division.

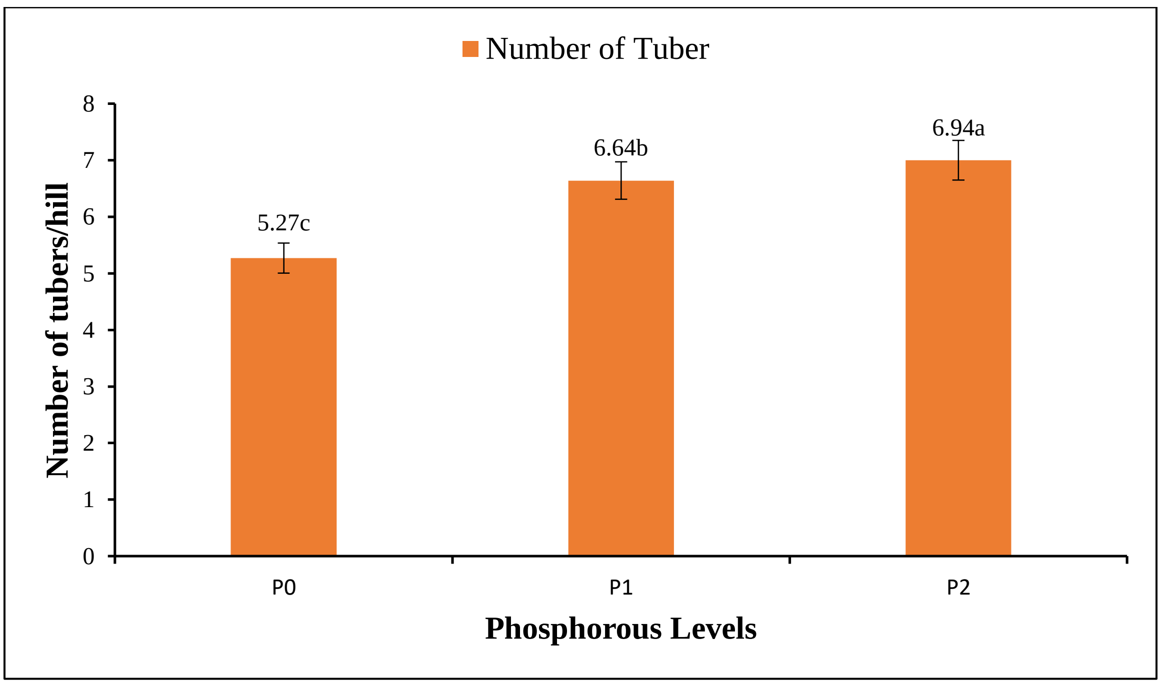


Fig. 7. Effect of phosphorous on the numbers of tubers hill^{-1}

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the number of tubers hill^{-1}

A considerable influence was observed on the number of tubers hill^{-1} with different boron (B) levels. (Figure 8. and Appendix IX). The highest number of tubers hill^{-1} (6.83) was achieved from treatment B_2 (3 kg B ha^{-1}) which was statistically different from others. And the lowest number of tubers hill^{-1} (5.59) resulted from the control treatment B_0 (0 kg B ha^{-1}) which was significantly different from others.

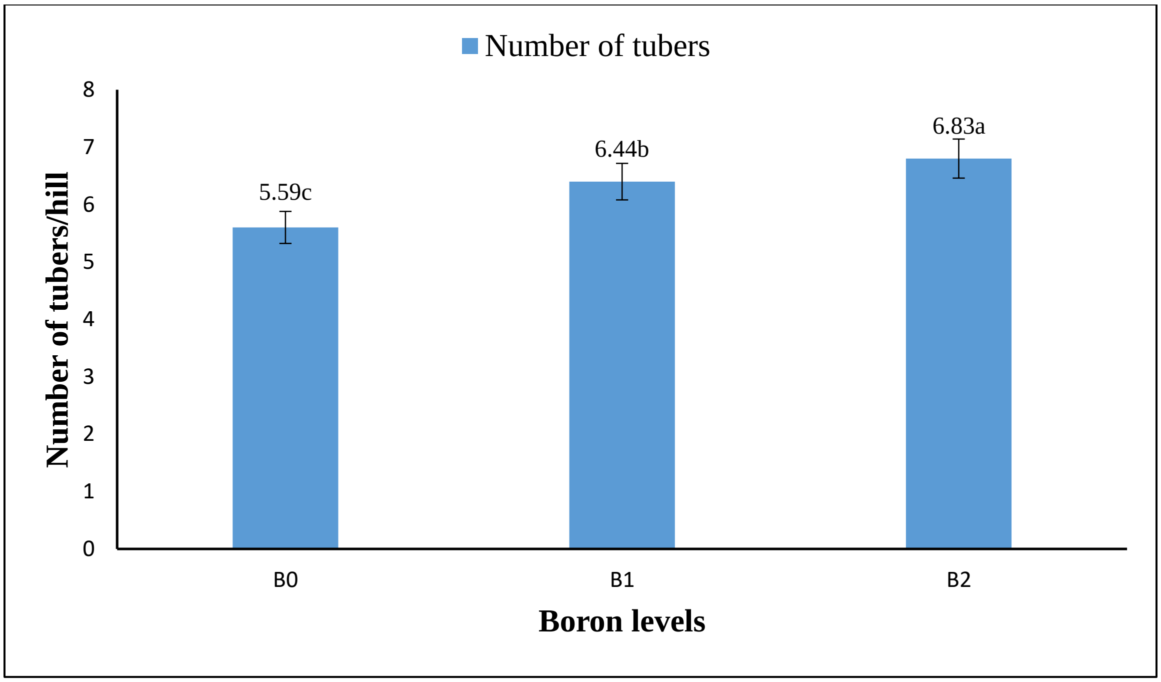


Fig. 8. Effect of boron the number of tubers hill^{-1}

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the number of tubers hill^{-1}

Remarkable variation was identified in the number of tubers hill^{-1} due to the combined effect of different phosphorous and boron levels (Table 4 and Appendix IX). The maximum number of tuber hill^{-1} (7.33) was found in the treatment combination P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) which was statistically similar to the treatment combination P_2B_1 (40 kg P ha^{-1} and 2 kg B ha^{-1}). The control treatment combination P_0B_0 (0 kg P ha^{-1} and 0 kg B ha-

^{1}) determined to have the lowest number (4.17) of tuber hill^{-1}. Which was significantly different from others.

4.2.2 Weight of tubers hill^{-1}

Effect of Phosphorous on the weight of tubers hill^{-1}

Different amounts of phosphorus (P) were recorded to significantly impact the variation in tuber weight plot^{-1} (Figure 9. and Appendix IX). The maximum weight of tubers hill^{-1} (489 gm) yielded from P_2 (40 kg P ha^{-1}) treatment, which was significantly different from other treatments. The lowest weight of tubers hill^{-1} (302.6 gm) was observed from the control treatment P_0 (0 kg P ha^{-1}) which was also significantly different from other treatments.

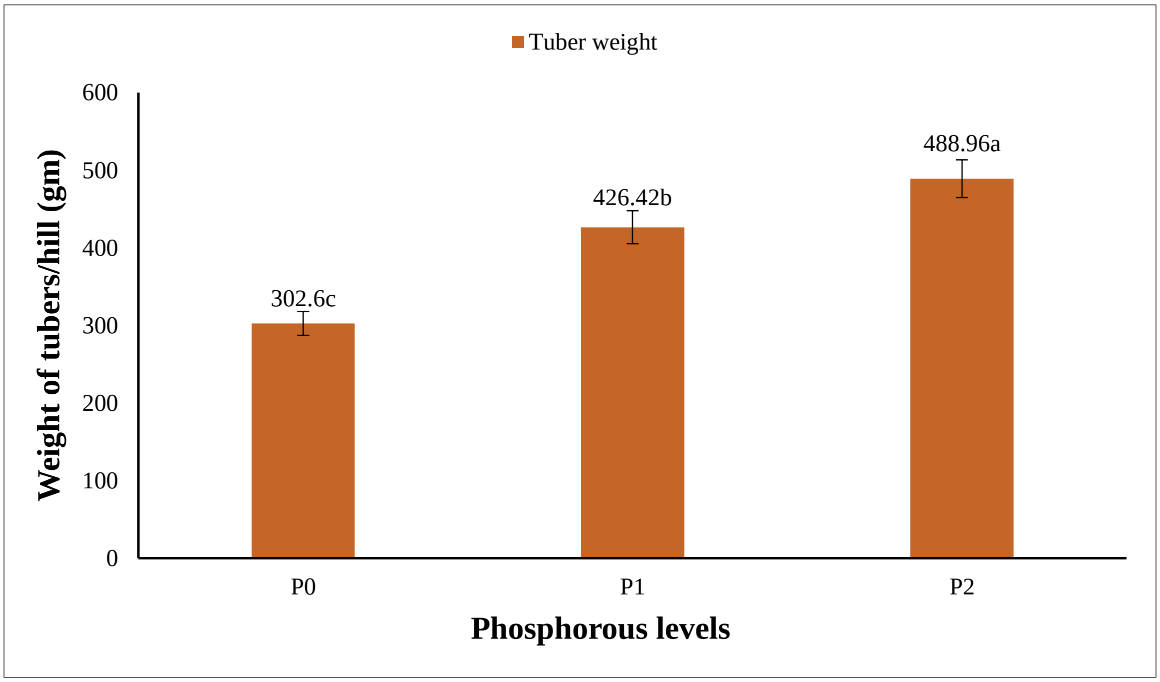


Fig. 9. Effect of phosphorous on the weight of tubers hill^{-1}

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the weight of tubers hill^{-1}

Different Boron (B) levels have a noticeable impact on the weight of tubers hill^{-1}. (Figure 10 and Appendix IX). The highest weight of tubers hill^{-1} (478.79 gm) resulted from treatment B_2 (3 kg B ha^{-1}) which was significantly different from the others. The control treatment B_0 (0 kg B ha^{-1}) had the lowest weight of tubers hill^{-1} (332.27 gm) which is significantly different from other treatments.

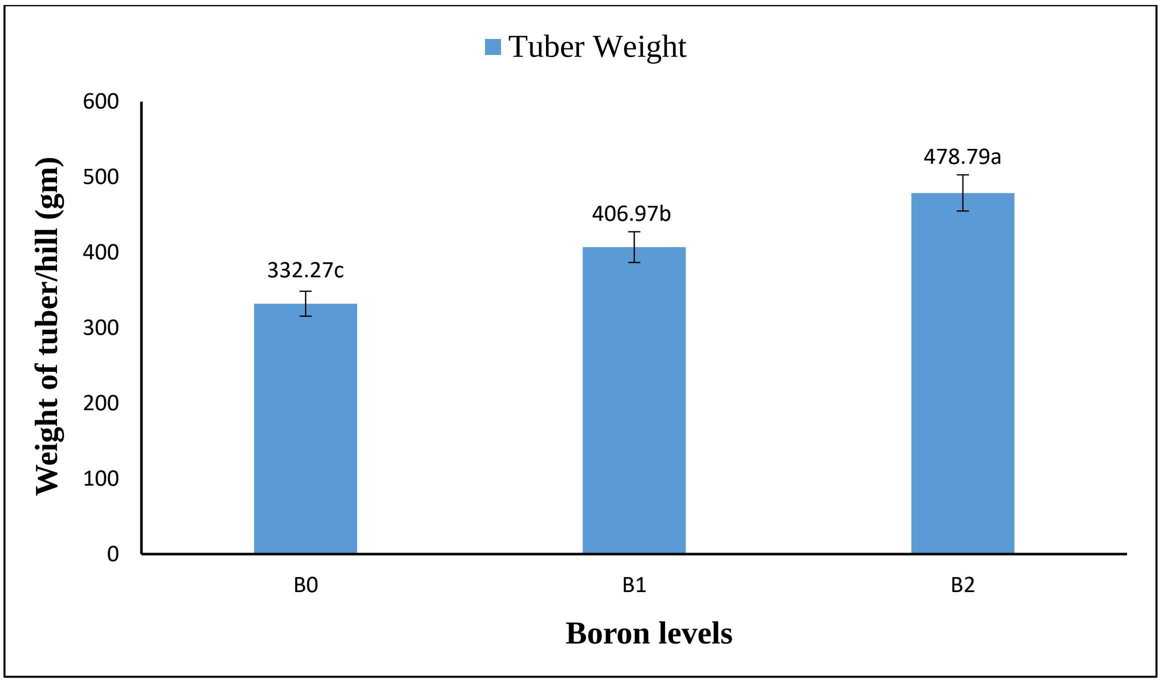


Fig. 10. Effect of boron on the weight of tubers hill^{-1}

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the weight of tubers hill^{-1}

The weight of tubers hill^{-1} varied significantly due to different treatment combinations (P) (Table 4. and Appendix IX). The highest weight of tubers hill^{-1} (552.1 gm) resulted from the treatment combination of P_2B_2 (0 kg P ha^{-1} and 3 kg B ha^{-1}) which was statistically different from other treatments. The lowest weight of tubers hill^{-1} (181.33 gm) was found in control treatment P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) which was statistically different from other treatments.

4.2.3 Weight of tubers plot^{-1}

Effect of phosphorous on the weight of tubers plot^{-1}

Different phosphorus (P) levels significantly impacted the variation in tuber weight plot^{-1} (Figure 11 and Appendix IX). The maximum weight (12.16 kg) of tubers plot^{-1} resulted from treatment P_2 (40 kg P ha^{-1}), which was significantly different from the other treatments. The lowest weight of tubers plot^{-1} (6.91 kg) was achieved from the control treatment P_0 (0 kg P ha^{-1}) and it was statistically different from other treatments. According to Mulubrhan (2004), increasing P treatment from 0 to 39.6 kg ha^{-1} enhanced overall tuber production by 24.27%.

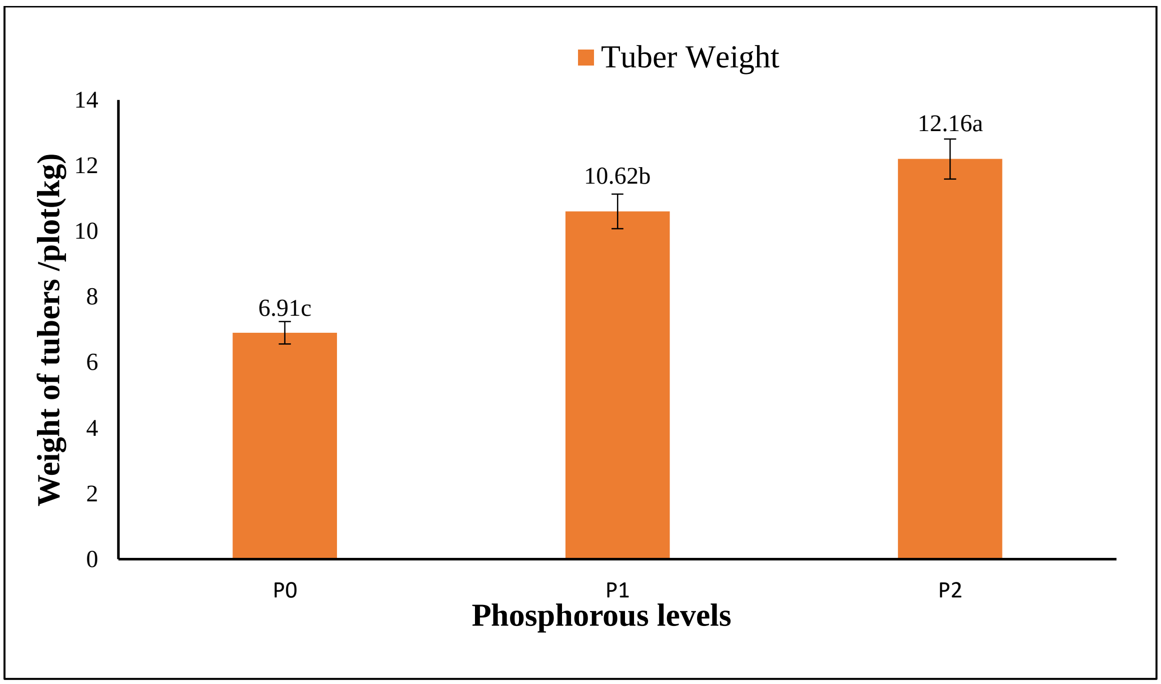


Fig. 11. Effect of phosphorous on the weight of tubers plot^{-1}

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the weight of tubers plot^{-1}

Variation in the weight of tubers plot^{-1} was noted as significantly influenced by different Boron (B) levels (Figure 12. And Appendix IX). The highest weight of the tubers (11.54 kg) was achieved from treatment B_2 (3 kg B ha^{-1}), it differed significantly from the other treatments. The lowest weight of tubers plot^{-1} (8.05 kg) was achieved from the control treatment B_0 (0 kg B ha^{-1}) and it differed significantly from all other treatments.

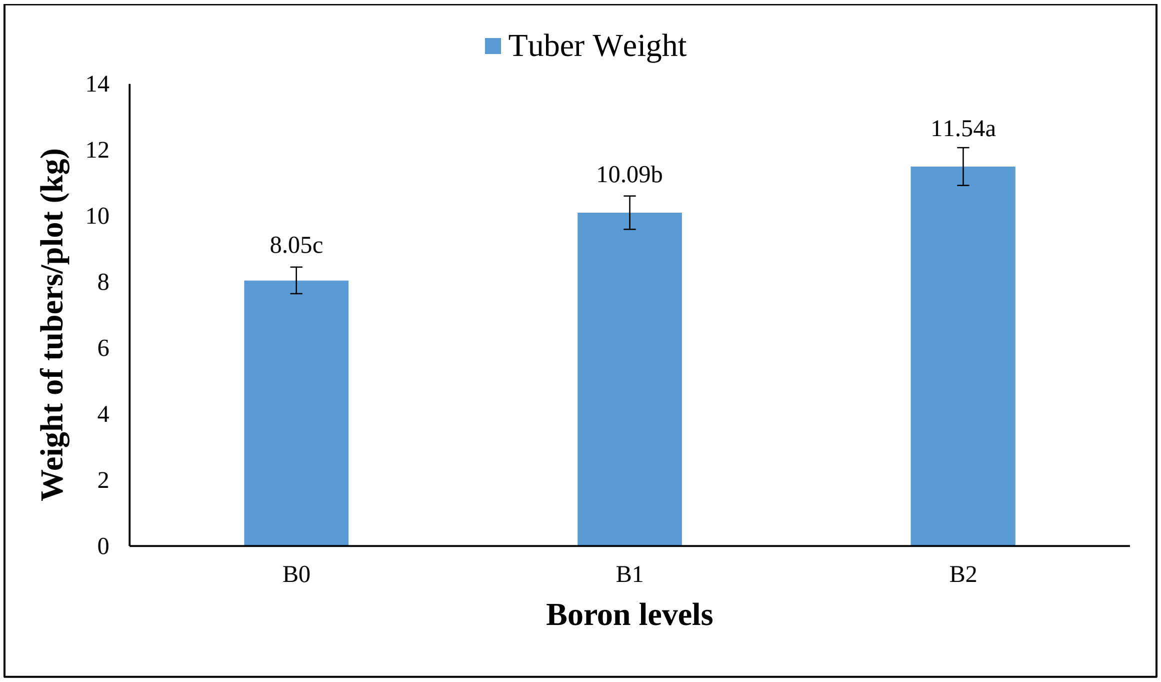


Fig. 12. Effect of boron on the weight of tuber plot^{-1}

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the weight of tuber plot^{-1}

The weight of tuber plot^{-1} varied significantly as a result of the combined impact of varying B and P levels. (Table 4 and Appendix IX). The highest tuber weight plot^{-1} was (13.57 kg) obtained from P_2B_2 (P_2 = 40 kg P ha^{-1} and B_2 = 3 kg B ha^{-1}) treatment which was significantly different from others. The lowest tuber weight (4.38 kg) resulted from the control treatment P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) and it significantly differs from other treatment combinations.

4.2.4 Tuber yield

Effect of phosphorous on tuber yield

Different amounts of phosphorus (P) have a significant effect on tuber production per hectare (Figure 13. and Appendix IX). The highest yield (30.47 t ha^{-1}) was observed from P_2 (40 kg P ha^{-1}) treatment, which was statistically different from other treatments. In line with the present finding, Zewide *et al.* (2012) have reported that increasing phosphorus application increased total tuber yield. The lowest yield was (17.30 t ha^{-1}) observed from the control treatment P_0 (0 kg P ha^{-1}).

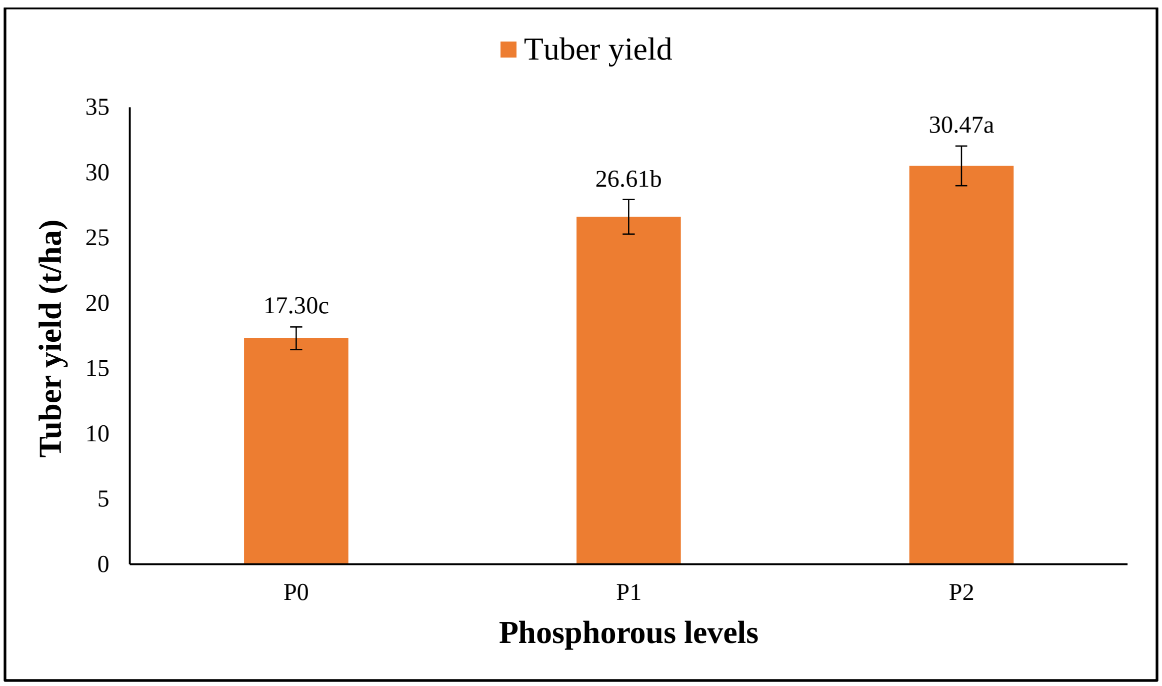


Fig. 13. Effect of phosphorous on tuber yield

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on tuber yield

Application of boron (B) fertilizer significantly impacted tuber yield ha^{-1} (Figure 14. and Appendix IX). Treatment B_2 (3 kg B ha^{-1}) produced the maximum tuber yield (28.92 t ha-

[1]), which varied considerably from the other treatments. The control treatment B_0 (0 kg B ha^{-1}) produced the lowest weight of tubers (20.17 t ha^{-1}), which varied substantially from all other treatments.

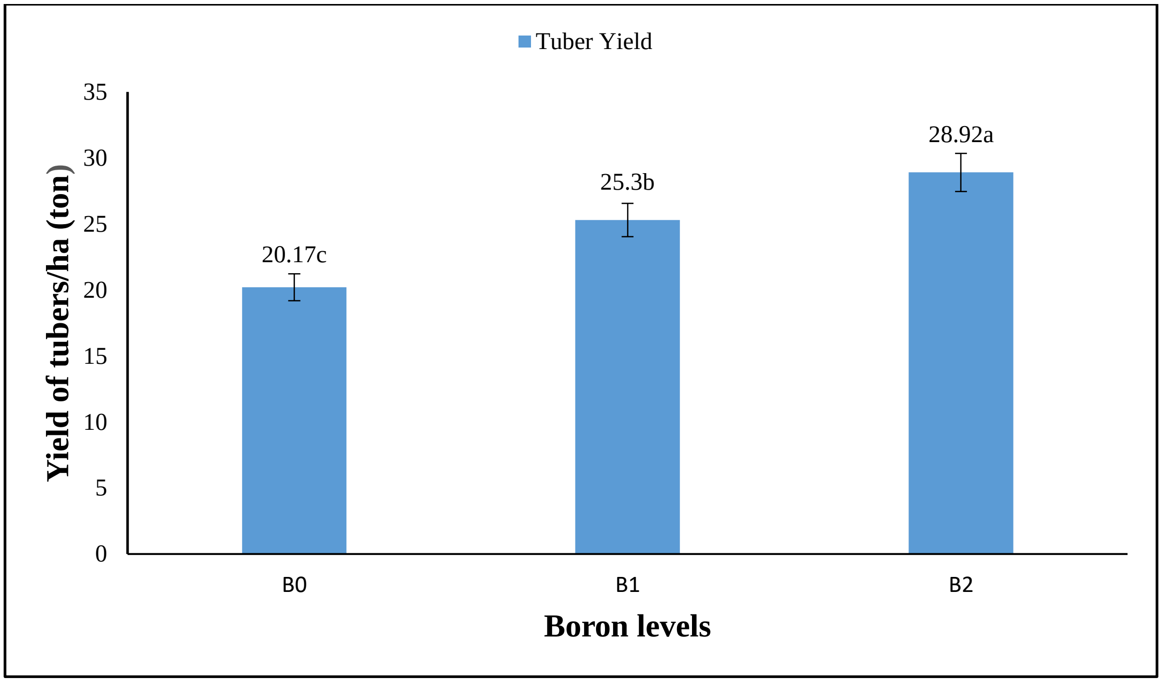


Fig. 14. Effect of boron on tuber yield

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on tuber yield

Remarkable variation was identified in tuber yield ha^{-1} due to the combined effect of different P and B levels (Table 4 and Appendix IX). The maximum tuber weight ha^{-1} (33.99 t ha^{-1})) was achieved from the P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) treatment, which was substantially different from the others. The control treatment P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) produced the least tuber weight (10.97 t ha^{-1}), which differed considerably from the other treatment combinations.

4.2.5 Marketable tuber yield

Effect of phosphorous on marketable tuber yield

Different amounts of phosphorus (P) have a significant effect on marketable tuber production per hectare (Figure 15. and Appendix IX). The highest yield ha^{-1} (26.63 t ha^{-1}) was observed from P_2 (40 kg P ha^{-1}) treatment, which was statistically different from others. The lowest yield was (13.60 t ha^{-1}) observed from the control treatment P_0 (0 kg P ha^{-1}).

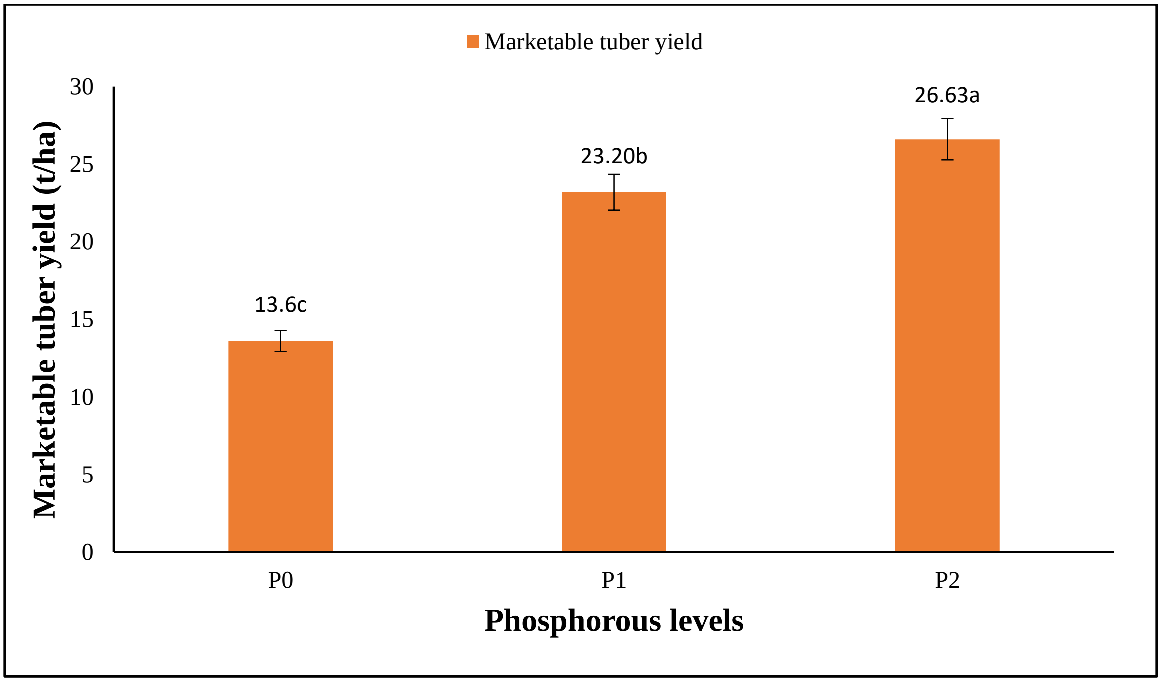


Fig. 15. Effect of phosphorous on marketable tuber yield

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on marketable tuber yield

Application of boron (B) fertilizer significantly impacted marketable tuber yield (Figure 16 and Appendix IX). Treatment B_2 (3 kg B ha^{-1}) produced the maximum marketable tuber weight (25.30 t ha^{-1}), which varied considerably from the other treatments. The control treatment B_0 (0 kg B ha^{-1}) produced the lowest weight of tuber (16.30 t ha^{-1}), which varied statistically from all other treatments.

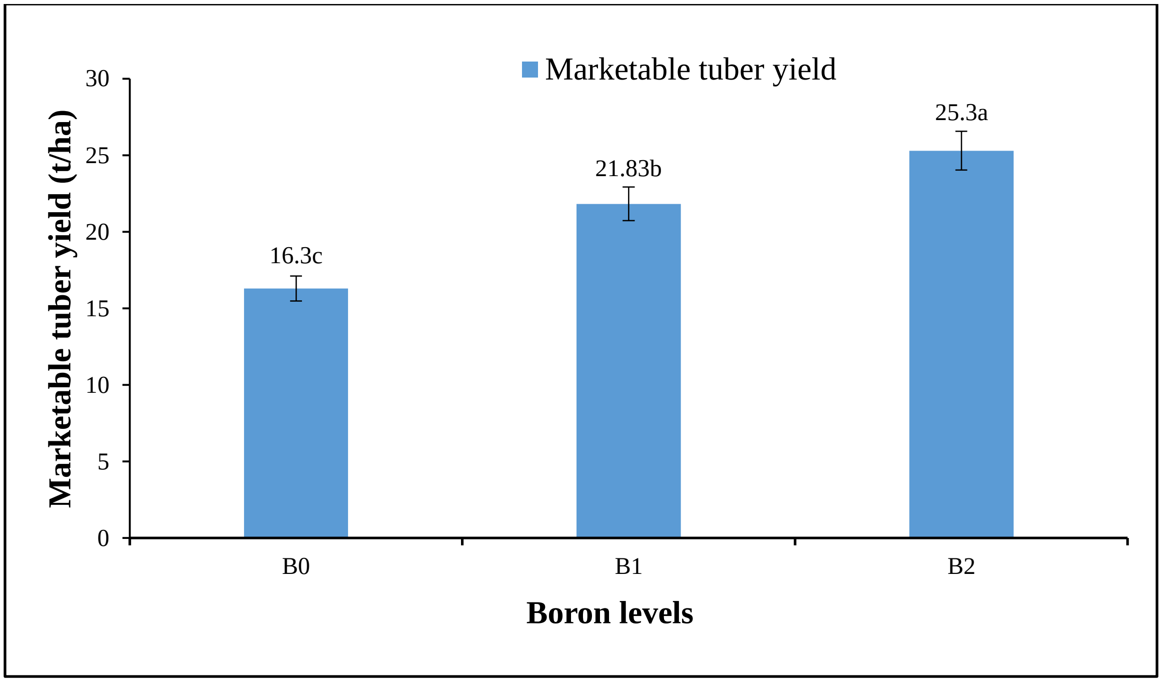


Fig. 16. Effect of boron on marketable tuber yield

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on marketable tuber yield

Significant variation was identified in tuber yield ha^{-1} due to the combined effect of different P and B levels (Table 4 and Appendix IX). The maximum tuber yield ha^{-1} (29.5 t ha^{-1}) was achieved from the P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) treatment, which was statistically different from the other treatment combinations. The control treatment P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) produced the lowest tuber weight (6.2 t ha^{-1}), which differed considerably from the other treatment combinations.

Table 4. The combined effect of phosphorous and boron on yield parameters and yield of potatoes

Treatments	Yield of potato				
	Number of Tuber $hill^{-1}$	Weight of tuber $hill^{-1}$ (gm)	Weight of tuber $plot^{-1}$ (kg)	Tuber yield (t ha^{-1})	Marketable yield (t ha^{-1})
P_0B_0	4.17f	181.33f	4.38g	10.97g	6.18g
P_0B_1	5.33e	316e	7.10f	17.78f	14.57f
P_0B_2	6.33d	410.47c	9.25e	23.16e	20.04e
P_1B_0	6.20d	392d	9.36e	23.45e	20.47e
P_1B_1	6.90ab	413.47c	10.69d	26.77d	22.81d
P_1B_2	6.83bc	473.80b	11.82c	29.60c	26.31c
P_2B_0	6.40cd	423.33c	10.42d	26.09d	22.23d
P_2B_1	7.10ab	491.43b	12.50b	31.31b	28.12b
P_2B_2	7.33a	552.10a	13.57a	33.99a	29.54a
$LSD_{0.05}$	0.44	17.83	0.48	1.20	1.14
CV(%)	4.06	2.54	2.82	2.82	3.12

In a column means having similar letter(s) are statistically identical and those having a dissimilar letter(s) differ significantly as per 0.05 level of probability

CV = Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

4.2.6 Size of potato tuber

4.2.6.1 The length of tuber

Effect of phosphorous on the length of potato tuber

The length of the tuber is significantly influenced by the applied quantity of phosphorus (P) (Figure 17 and Appendix X). The highest length of the tuber (18.37 cm) resulted from P_2 (40 kg P ha^{-1}) treatment, which was statistically different from others. Minimum tuber length (15.91 cm) was achieved from the control treatment P_0 (0 kg P ha^{-1}).

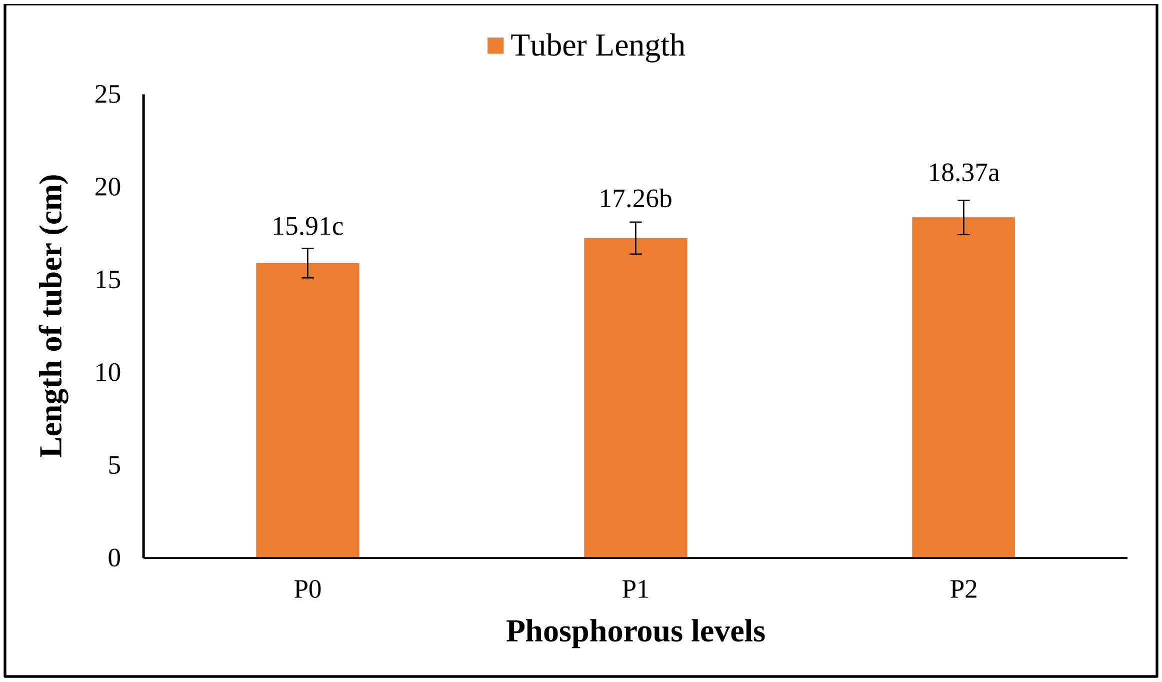


Fig. 17. Effect of phosphorous on Length of potato tuber

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the length of potato tuber

The effect of different doses of boron did not show a statistically significant variation on the length of potato tuber (Figure 18. And Appendix X).

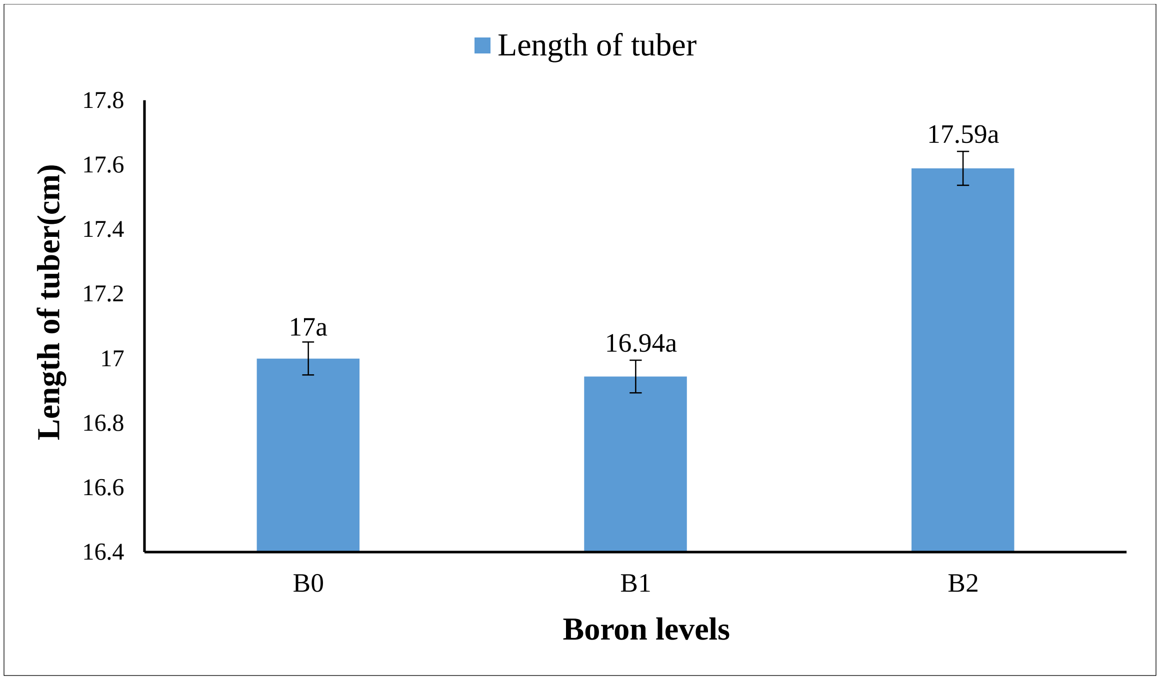


Fig. 18. Effect of boron on the length of potato tuber

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the length of potato tuber

The combined impact of various P and B levels failed to produce a significant change in tuber length. (Table 5. And Appendix X).

4.2.6.2 The width of the tuber

Effect of phosphorous on the width of potato tuber

The width of the tuber was significantly influenced by different levels of phosphorus (P) (Figure 19 and Appendix X). The highest width of the tuber (15.57 cm) resulted from P_2 (40 kg P ha^{-1}) treatment, which was statistically different from others. The lowest tuber width (13.33 cm) was achieved from the control treatment P_0 (0 kg P ha^{-1}).

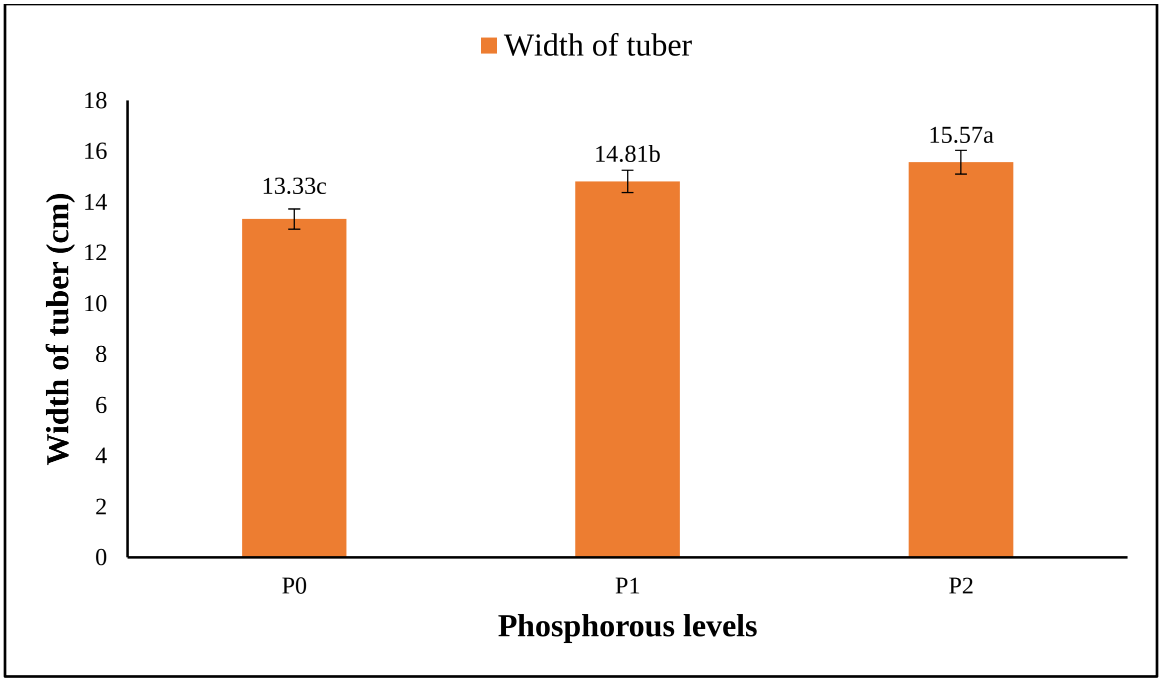


Fig. 19. Effect of phosphorous on the width of potato tuber

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on the width of potato tuber

The effect of different doses of boron shows a statistically significant variation in the width of potato tuber (Figure 20 and Appendix X). The highest width (15.03 cm) was observed in treatment B_2 (3 kg B ha^{-1}) and the lowest width (14.07 cm) was observed in B_1 (2 kg B ha^{-1}) treatment which is statistically similar with B_0 (control) tratment.

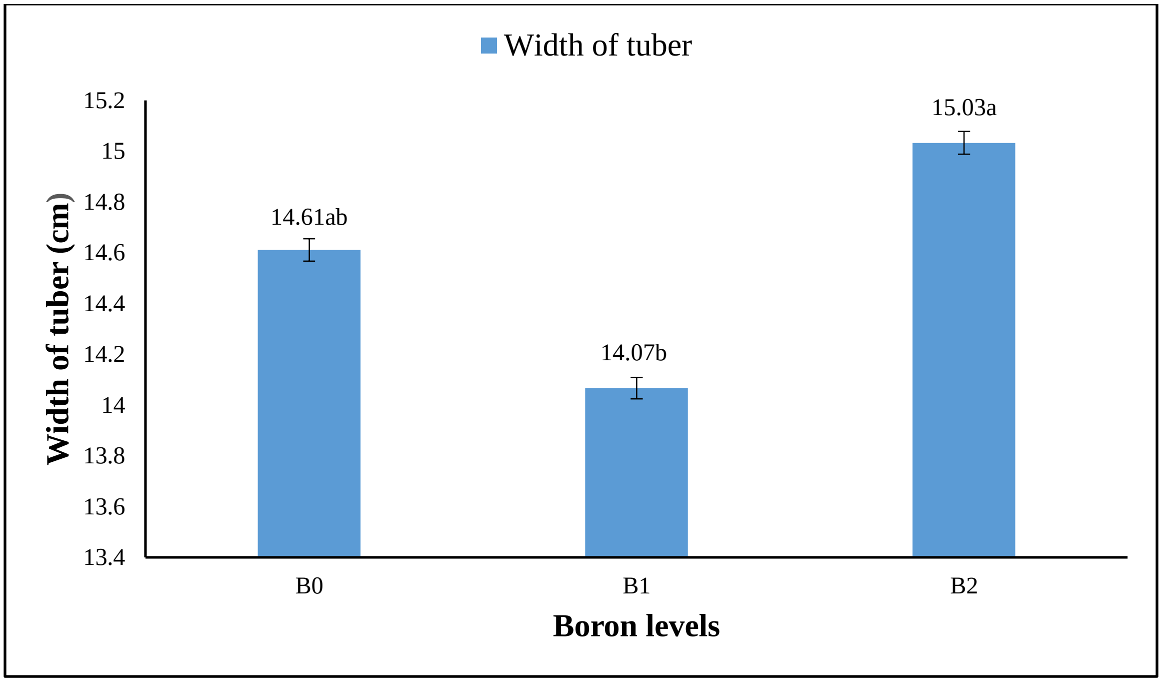


Fig. 20: Width of tuber influenced by Boron

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on the width of potato tuber

The combined impact of various P and B levels produces a significant change in tuber width (Table 5. And Appendix X). The highest width (16.13 cm) was obtained by treatment combination P_2B_2 (P_2 = 40 kg P ha^{-1} and B_2 = 3 kg B ha^{-1}), whereas P_0B_0 (P_0 = 0 kg P ha^{-1} and B_0 = 0 kg B ha^{-1}) treatment produced the lowest width of tuber (12.13 cm).

Table 5. The combined effect of phosphorous and boron on the size of potato tuber

Treatments	Size of tuber	
	Length of tuber (cm)	Width of tuber (cm)
P_0B_0	15.00e	12.13e
P_0B_1	15.73de	13.00de
P_0B_2	17.00bcd	14.10cd
P_1B_0	17.87abc	15.77ab
P_1B_1	16.83cd	14.57c
P_1B_2	17.07bcd	14.87bc
P_2B_0	18.13abc	15.93ab
P_2B_1	18.27ab	14.63c
P_2B_2	18.70a	16.13a
$LSD_{0.05}$	1.38	1.11
CV (%)	4.65	4.39

In a column means having similar letter(s) are statistically identical and those having a dissimilar letter(s) differ significantly as per 0.05 level of probability

CV = Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

4.3 Postharvest soil analysis

4.3.1 Soil pH

Effect of phosphorous on soil pH in postharvest soil

The impact of various phosphorous dosages causes a statistically significant difference in soil pH in postharvest soil (Figure 21 and Appendix XI). Control treatment P_0 (0 kg P ha^{-1}) shows the highest soil pH (6.3). The lowest pH (6.19) was observed in P_2 (40 kg P ha^{-1}) treatment, which was identical to P_1 (30 kg P ha^{-1}) treatment.

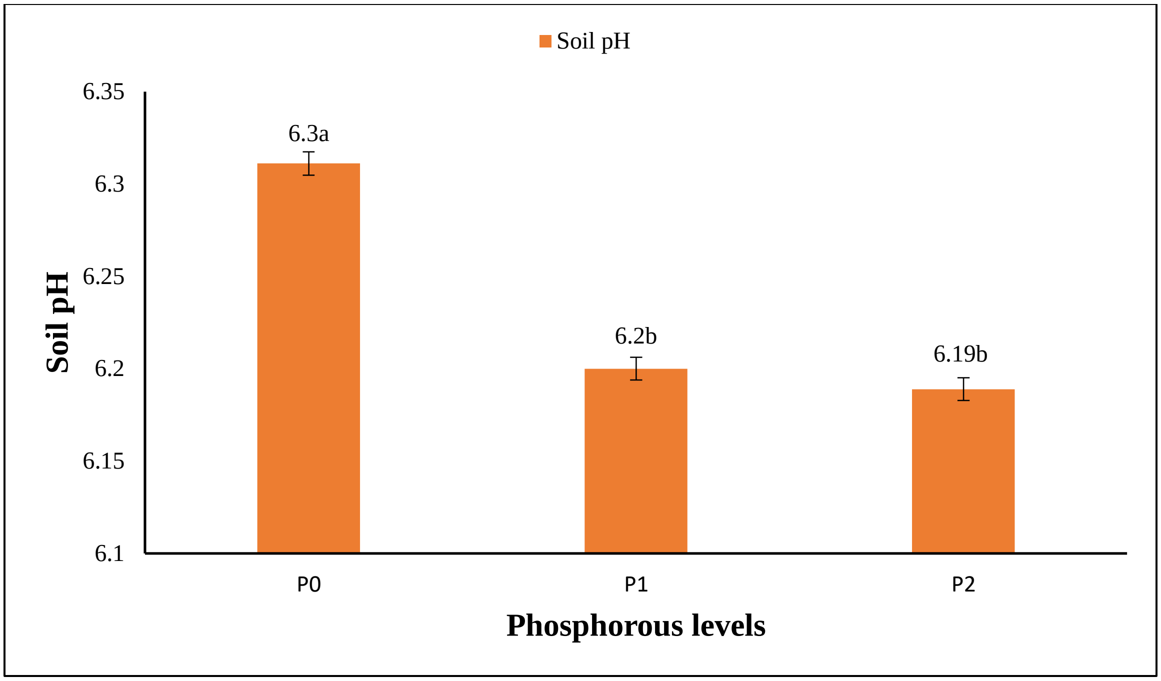


Fig. 21. Effect of phosphorous on soil pH in postharvest soil

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on soil pH in postharvest soil

There is a statistically significant change in soil pH as a result of the effects of different boron doses (Figure 22 and Appendix XI). Maximum soil pH (6.2) was observed in B_0 (0 kg B ha^{-1}) treatment. B_2 (3 kg B ha^{-1}) treatment showed the lowest level of pH, which was identical to B_1 (2 kg B ha^{-1}) treatment.

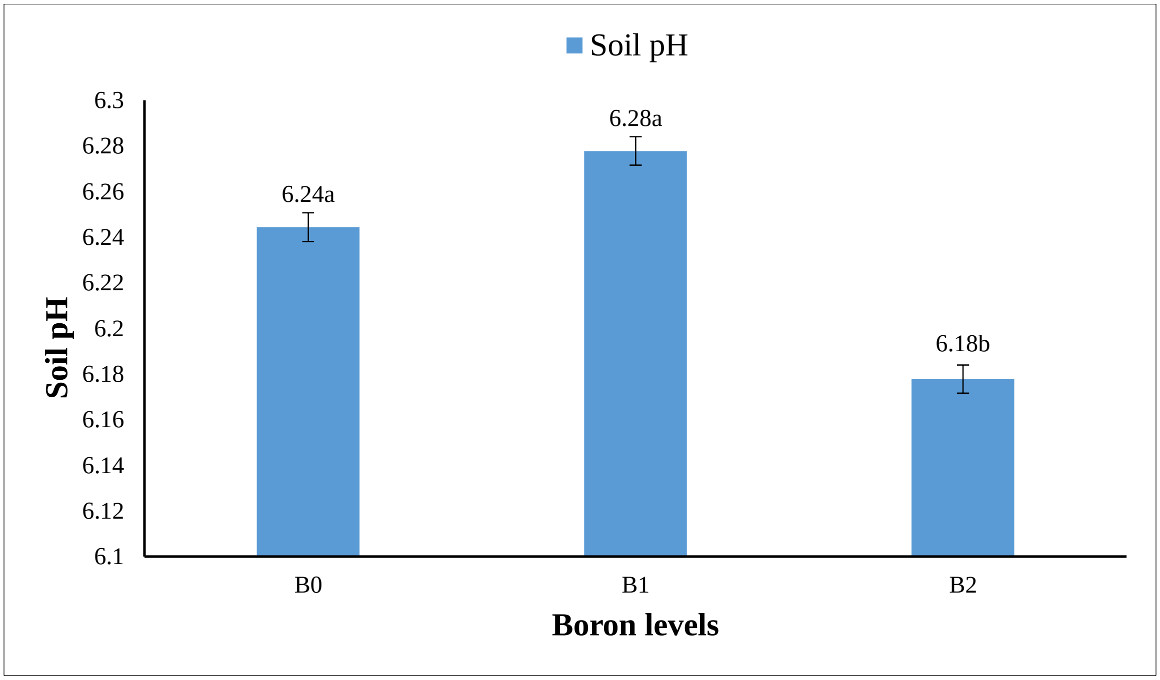


Fig. 22. Effect of boron on soil pH in postharvest soil

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron in postharvest soil pH

A statistically significant variation in soil pH is observed by the effects of combined treatments of phosphorus and boron doses (Table 6 and Appendix XI). The highest soil pH was observed in P_0B_2 (0 kg P ha^{-1} and 3 kg B ha^{-1}), and the lowest pH resulted from P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}).

4.3.2 Organic matter

Effect of phosphorous on organic matter in postharvest soil

On soil organic matter, there was no statistically significant difference in the effects of the various phosphorous dosages (Figure 23 and Appendix XI). The highest organic matter percentage was (1.14) seen in the P_1 treatment (30 kg P ha^{-1}). Whereas the lowest organic matter percentage (1.12) was seen in the P_2 treatment (40 kg P ha^{-1}).

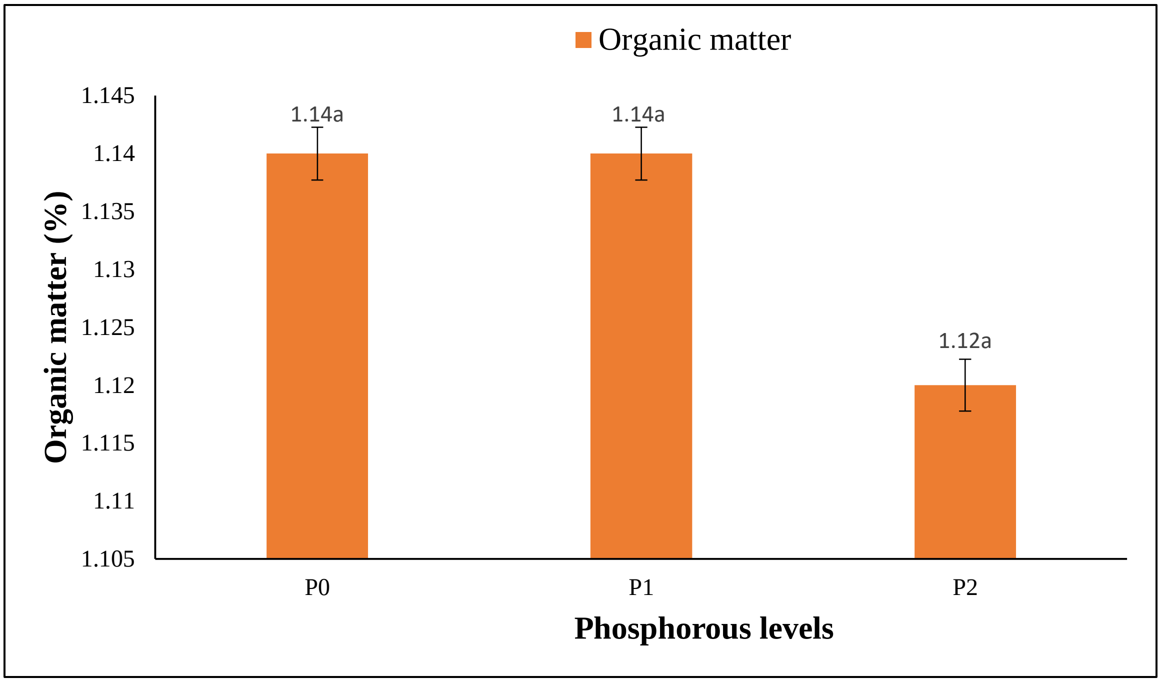


Fig. 23. Effect of phosphorous on organic matter (%) in postharvest soil

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on organic matter in postharvest soil

The impact of boron was not statistically significant on soil organic matter (Figure 24 and Appendix XI). Control treatment B_0 (0 kg B ha^{-1}) had the highest organic matter percentage (1.123) and The B_1 treatment (2 kg B ha^{-1}) had the lowest organic matter percentage (1.119).

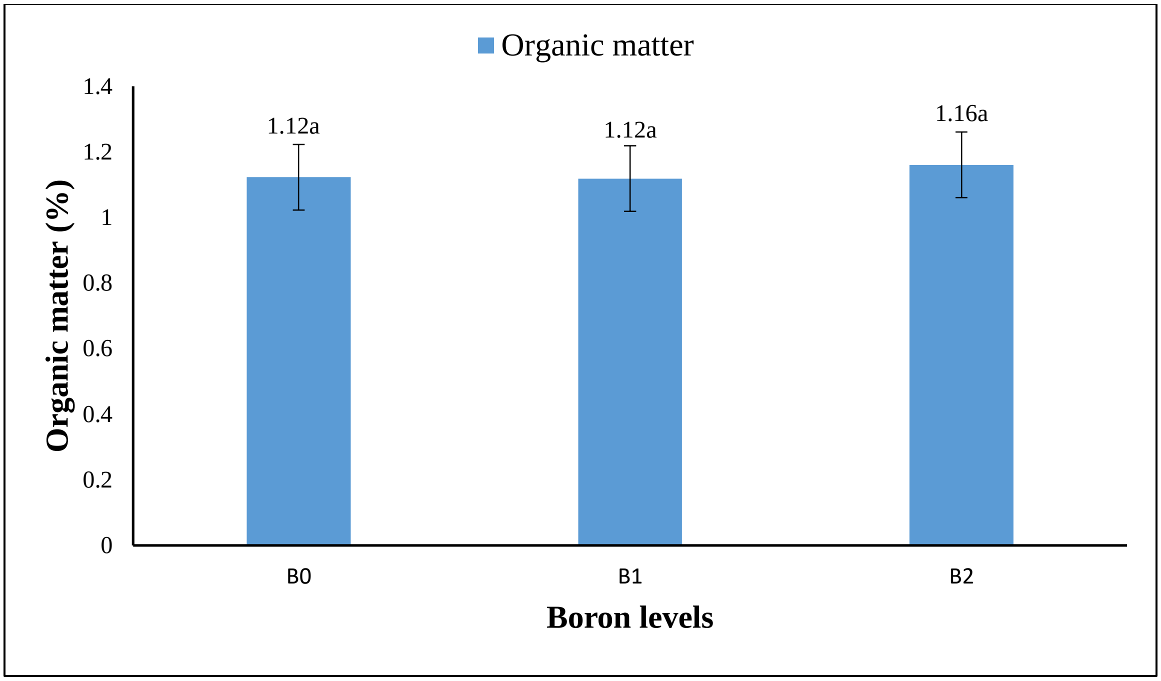


Fig. 24. : Effect of boron on organic matter in postharvest soil

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron in organic matter in postharvest soil

There is no statistically significant difference in organic matter percentage in soil caused by the combined impacts of phosphorus and boron dosage (Table 6 and Appendix XI). Maximum organic matter percentage (1.19) observed in P_2B_2 (P_2 = 40 kg P ha^{-1} and B_2 = 3 kg B ha^{-1}) treatment. And lowest organic matter percentage (1.08) was observed in P_2B_0 (P_2 = 40 kg P ha^{-1} and B_0 = 0 kg B ha^{-1}) and P_2B_1 (P_2 = 40 kg P ha^{-1} and B_1 = 2 kg B ha^{-1}) treatments.

4.3.3 Available phosphorous (ppm)

Effect of phosphorous on available phosphorous in postharvest soil

A statistically significant variation in available phosphorous in postharvest soil is brought on by the effects of different phosphorus doses (Figure 25 and Appendix XI). The lowest amount of available phosphorous (20.08 ppm) resulted from the control treatment (0 kg P ha^{-1}), and the highest amount of phosphorous (25.98 ppm) is seen in P_2 treatment (40 kg P ha^{-1}). All treatments are statistically different from one another.

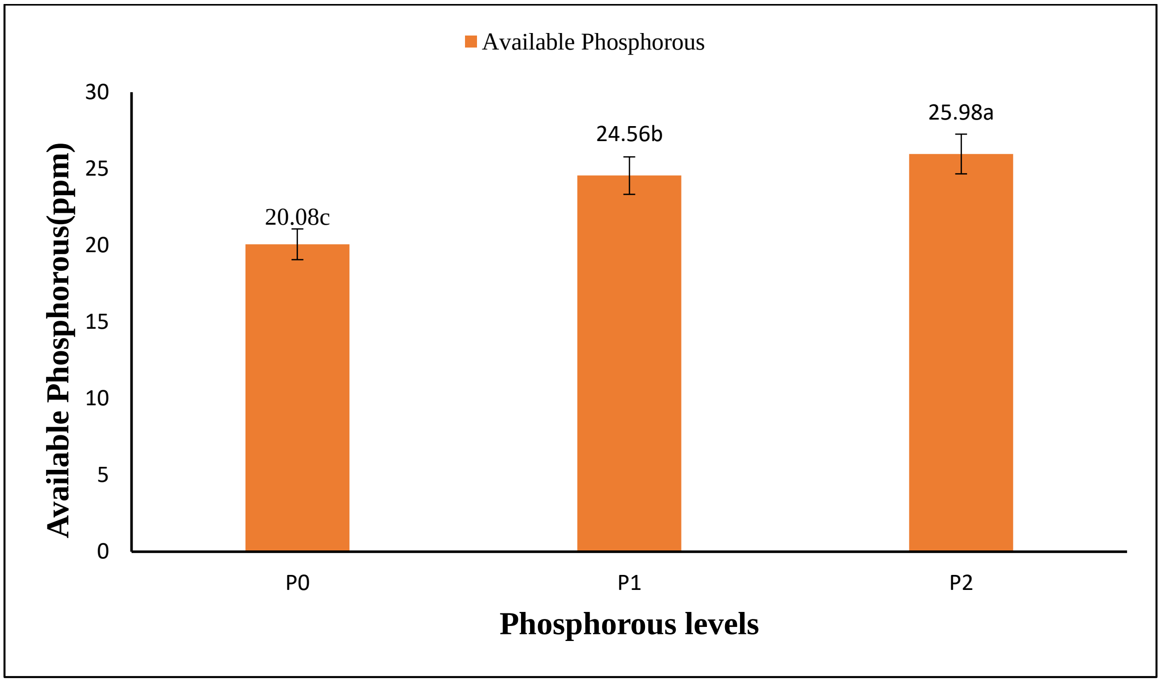


Fig. 25. Effect of phosphorous on available phosphorous in postharvest soil

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on available phosphorous in postharvest soil

Different boron doses have a statistically significant influence on available phosphorous in postharvest soil (Figure 26 and Appendix XI). The B_2 (B_2 = 3 kg B ha^{-1}) treatment produces the greatest quantity of available phosphorus (27.79 ppm), while the control treatment (0 kg B ha^{-1}) produces the least amount (18.14 ppm).

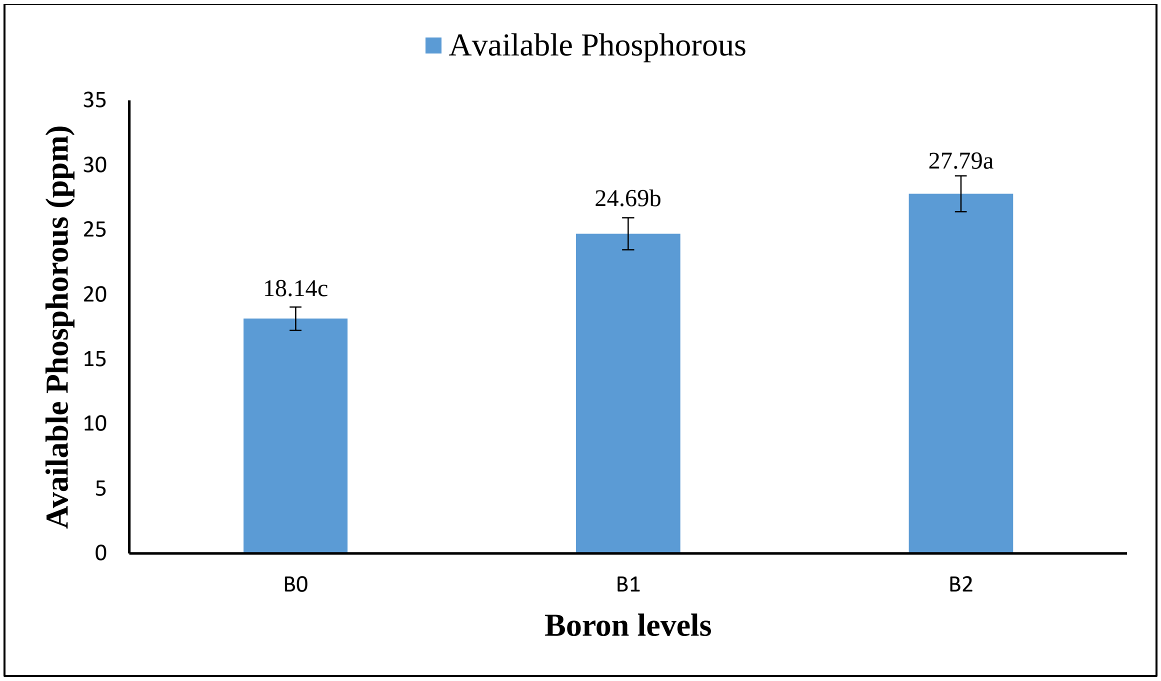


Fig. 26. : Effect of boron on available phosphorous in postharvest soil

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on available phosphorous in postharvest soil

The influence of varying phosphorous and boron concentrations on postharvest soil phosphorus availability is substantial (Table 6 and Appendix XI). The treatment combination P_2B_2 (P_2 = 40 kg P ha^{-1} and B_2 = 3 kg B ha^{-1}) produces the greatest quantity of available phosphorus (32.27 ppm), while the control treatment (0 kg P ha^{-1} and 0 kg B ha^{-1}) produces the least amount of available P (8.75 ppm).

4.3.4 Available sulphur (ppm)

Effect of phosphorous on available sulphur in postharvest soil

Different phosphorous levels have a statistically significant influence on available sulphur in postharvest soil (Figure 27 and Appendix XI). The highest amount of sulphur (8.85 ppm) was resulted from P_2 treatment (40 kg P ha^{-1}). And lowest amount of available Sulphur (2.08 ppm) was found from P_0 treatment (0 kg P ha^{-1}).

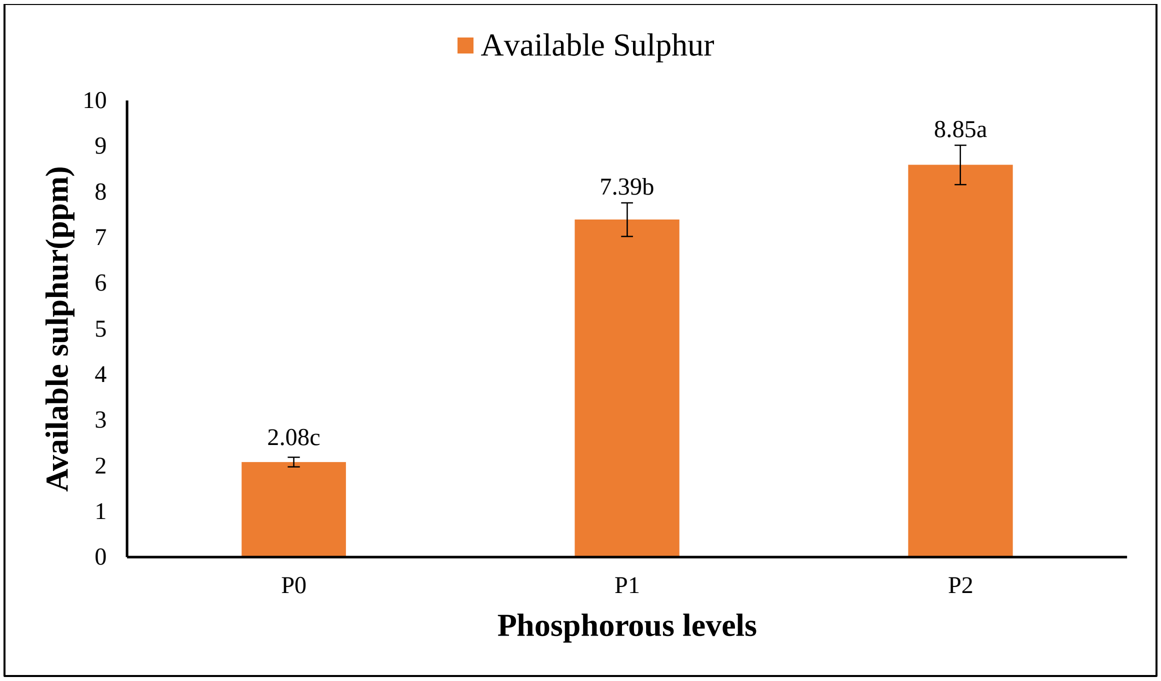


Fig. 27. Effect of phosphorous on available sulphur in postharvest soil

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}

Effect of boron on available sulphur in postharvest soil

On available sulphur in postharvest soil, there was a statistically significant difference in the effects of the various boron levels (Figure 28 and Appendix XI). The lowest amount of sulphur (5.85 ppm) was observed in control treatment. And highest amount of sulphur (6.28 ppm) resulted in B_2 (2 kg B ha^{-1}) treatment.

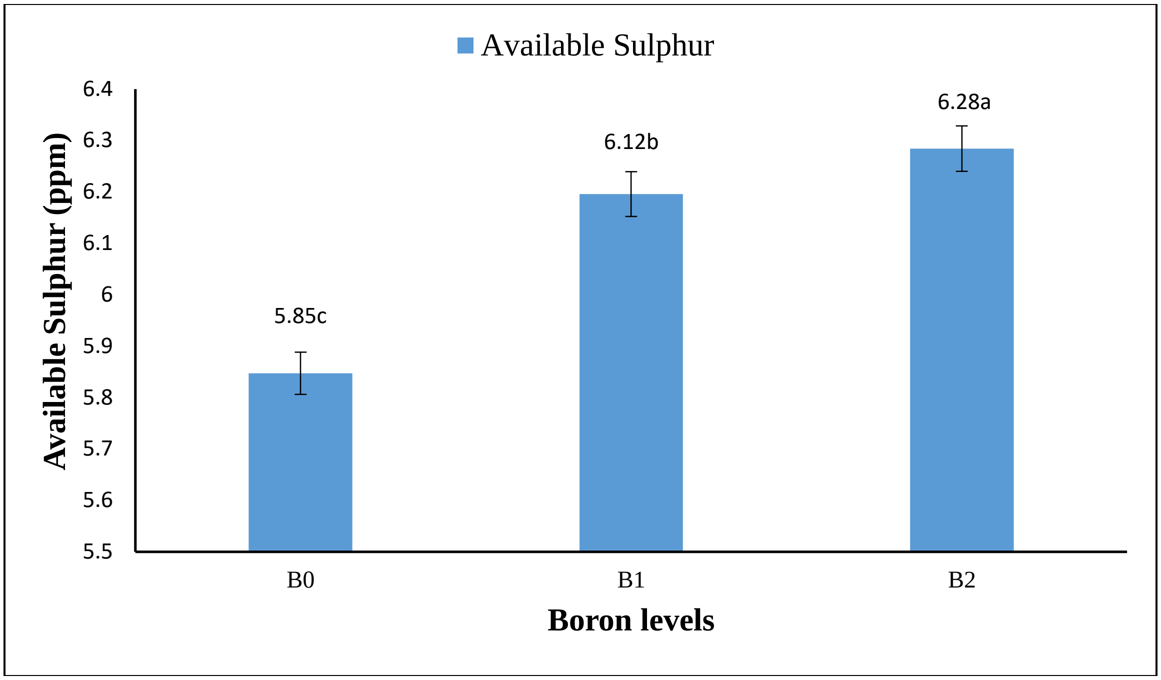


Fig. 28. : Effect of boron on available sulphur in postharvest soil

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

The combined effect of phosphorous and boron on available sulphur in postharvest soil

There was a statistically significant difference in the impacts of the treatment combinations of phosphorous and boron levels on the amount of available sulphur that was available in post-harvest soil (Table 6 and Appendix XI). The highest amount of sulphur (9.84pp m) resulted in P_2B_2 (40 kg P ha^{-1} and 3 kg B ha^{-1}) treatment. And lowest sulphur amount (1.35 ppm) was found from control treatment combination P_0B_0 (0 kg P ha^{-1} and 0 kg B ha^{-1}) treatment.

Table 6. Effect of phosphorous and boron fertilizer on soil pH, available phosphorus, and available sulphur concentrations in postharvest soil in potato field

Treatment	Soil pH	Organic matter (%)	Available phosphorous (ppm)	Available Sulphur (ppm)
P_0B_0	6.3ab	1.14ab	8.75e	1.35g
P_0B_1	6.3ab	1.14ab	27.13b	2.46f
P_0B_2	6.33a	1.14ab	24.36cd	2.43f
P_1B_0	6.20bc	1.15ab	23.00d	8.07c
P_1B_1	6.27ab	1.14ab	23.94d	7.51d
P_1B_2	6.13dc	1.14ab	26.75bc	6.58e
P_2B_0	6.23abc	1.08b	22.66d	8.12a
P_2B_1	6.27ab	1.08b	23.00d	8.62b
P_2B_2	6.07d	1.19a	32.27a	9.84a
$LSD_{0.05}$	0.11	0.10	2.65	0.50
CV (%)	0.98	5.14	6.51	4.76

In a column means having similar letter(s) are statistically identical and those having a dissimilar letter(s) differ significantly as per 0.05 level of probability

CV= Coefficient of variation, DAP = Days after planting

P_0 = Control (0 kg P ha^{-1}), P_1 = 30 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}.

B_0 = Control (0 kg B ha^{-1}), B_1 = 2 kg B ha^{-1}, B_2 = 3 kg B ha^{-1}

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The experiment was carried out at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207, from November 2021 to February 2022 to investigate the impact of phosphorous and boron on the growth and yield of potato. A potato variety Diamant (BARI Alu-7) was used with three levels of P (0, 30, and 40 kg/ha) and three levels of B (0, 2, and 3 kg/ha). The experiment was laid out into RCBD and data were collected on different parameters and analyzed using Statistix 10 software.

Different phosphorous levels showed a significant variation in different parameters of potato. The highest plant height (36.19 and 49.08 cm at 30 and 60 DAP respectively), number of leaves hill^{-1} (26 and 90.4 at 30 and 60 DAP, respectively), stem number hill^{-1} (4.51 and 5.22 at 30 and 60 DAP respectively), number of tubers hill^{-1} (6.94), the weight of tuber hill^{-1} (488.96 gm), weight of tuber plot^{-1} (12.16 kg), highest yield (30.47 t ha^{-1}), highest marketable yield (26.63 t ha^{-1}), length of the tuber (18.37 cm) and width of the tuber (15.57cm) resulted from the treatment P_2 (40 kg P ha^{-1}). On the other hand, the lowest plant height (28.09 cm and 41.64 cm at 30 and 60 DAP respectively), number of leaves hill^{-1} (18.22 and 60.51 at 30 and 60 DAP, respectively), stem number hill^{-1} (3.24 and 4.01 at 30 and 60 DAP respectively), tuber number hill^{-1}(5.27), weight of tuber hill^{-1} (302.6 gm), weight of tuber plot^{-1} (6.91kg), the yield (17.30 t ha^{-1}), marketable yield (13.598 ton ha^{-1}), tuber length (15.91 cm), and tuber width (13.33 cm) were obtained from the control treatment.

Different doses of P fertilizer showed a significant variation in pH, available P, and available Sulphur on postharvest soil. The highest available P (25.98 ppm) and available S (8.86 ppm) were obtained from the P_2 treatment but the highest pH (6.3) was obtained from the control treatment. While lowest pH (6.2), was obtained from P_2 treatment and lowest available P (20.08 ppm) and available S (2.08ppm) resulted from control treatment. Organic matter (%) was insignificant in the case of P.

Regarding boron fertilizer, several potato properties significantly varied with different B levels. The highest plant height (34.70 and 47.16 cm at 30 and 60 DAP respectively), number of leaves $hill^{-1}$ (26.4 and 88.2 at 30 DAP, and 60 DAP respectively), stem number $hill^{-1}$ (4.6 and 5.3 at 30 and 60 DAP respectively), tuber number $hill^{-1}$ (6.8), weight of tuber $hill^{-1}$ (478.8 gm), weight of tuber $plot^{-1}$ (11.5 kg), highest yield (28.92 t ha^{-1}), highest marketable yield (25.3 t ha^{-1}), length of the tuber (17.59 cm) and width of the tuber (15.03 cm) resulted from the treatment B_2 (3 kg B ha^{-1}). On the other hand, the lowest plant height (29.39 cm and 43.44 cm at 30 and 60 DAP respectively), number of leaves $hill^{-1}$ (18.6 and 63.2 at 30 and 60 DAP, respectively), stem number $hill^{-1}$ (3.3 and 3.7 at 30 and 60 DAP respectively), tuber number $hill^{-1}$(5.6), weight of tuber $hill^{-1}$ (332.2 gm), weight of tuber $plot^{-1}$ (8.053 kg), the yield (20.17 t ha^{-1}), marketable yield (16.3 ton ha^{-1}), tuber length (16.94cm) were obtained from control treatment. Though lowest tuber width (14.07 cm) resulted from B_1 treatment (2 kg B ha^{-1}). Different doses of B fertilizer showed significant variations on pH, available P and available S on postharvest soil. Highest available P (27.97 ppm), highest available S (6.28 ppm), lowest pH (6.18) were obtained from B_2 treatment (3 kg B ha^{-1}). Lowest available P (18.14 ppm), lowest available S (5.85) and highest pH resulted from control treatment. Organic matter (%) was insignificant in case of B.

Considering the combined effect of P and B the highest plant height (37.47 and 50.70 cm at 30 and 60 DAP respectively), number of leaves $hill^{-1}$ (28.93 and 109.00 at 30 and 60 DAP, respectively), highest stem number $hill^{-1}$ (5 and 6.17 at 30 and 60 DAP respectively), tuber number $hill^{-1}$ (7.33), weight of tuber $hill^{-1}$ (552.10 gm), weight of tuber $plot^{-1}$ (13.57 kg), highest yield (33.99 t ha^{-1}), highest marketable yield (29.54 t ha^{-1}), length of the tuber (18.70 cm) and width of the tuber (16.13 cm) resulted from the P_2B_2 treatment combination. On the other hand, the lowest plant height (21.5 and 38.10 cm at 30 and 60 DAP respectively), number of leaves $hill^{-1}$ (13.40 and 51.53 at 30 and 60 DAP, respectively), stem number $hill^{-1}$ (2.47 and 3.17 at 30 and 60 DAP respectively), tuber number $hill^{-1}$ (4.17), weight of tuber $hill^{-1}$ (302.60 gm), weight of tuber $plot^{-1}$ (4.38 kg), the yield (17.30 t ha^{-1}), marketable yield (13.60 t ha^{-1}), tuber length (15 cm), and tuber width (12.13 cm) were obtained from control treatment combination P_0B_0.

On postharvest soil, highest available P (32.27 ppm) and available S (9.84 ppm) were obtained from P_2B_2 treatment but highest pH (6.33) was obtained from P_0B_2 treatment. While the lowest pH (6.07) was obtained from P_2B_2 treatment and the lowest available P

(8.75 ppm) and available S (1.35 ppm) resulted from the control treatment combination. Organic matter (%) was insignificant in case of combined treatment of P and B.

According to the aforementioned findings, P and B had a favorable impact on the overall physiology, growth, and yield of the potato. P_2 (40 kg P ha^{-1}) and B_2 (3 kg B ha^{-1}) showed greater height, growth and yield at all stages of development and yield. Thus, it may be suggested that P_2 (40 kg P ha^{-1}) and B_2 (3 kg B ha^{-1}) were superior for potato development and production.

Future line of work:

This Experimentation was limited to a single growing season; further validation of the results is necessary before making a recommendation. Given the circumstances of the present investigation, more research may be recommended in the following areas:

1. Such research is required in Bangladesh's various agroecological zones (AEZ) for regional adaptation and other performance.
2. A different degree of Phosphorous and boron fertilizer may be used to determine more specific dosages.
3. Various fertilizers may be used to improve results.

CHAPTER VI

REFERENCES

Allison J. H., J. H. Flower, E. J. Allen, 2001. Effects of soil- and foliar- applied phosphorus fertilizers on the potato (*Solanum tuberosum*) crop. *J agri sci*. 137:379-395

Asseffa, N., 2005. Response of two improved potato varieties to nitrogen and phosphorus application. An MSc Thesis presented to School of Graduate studies Alemaya University. pp: 75.

Atkinson D, Geary B, Stark J, Love S, Windes J (2003). Potato varietal responses to nitrogen rate and timing in Idaho Potato Conference on January 22, p. 59.

Awasthi, A. P. and Grewal, J. S. (1977). Response of potato tuber to micronutrient application. *Indian Farm.* **39(6):**13-15.

B. Aloo, (2021). Characterization of Rhizobacteria and Their Formulation into Biofertilizers for Potato *(Solanum tuberosum* L.*) Growth Promotion in Tanzania*, NM-AIST, Arusha, Tanzania.

Balemi T., (2009). Effect of phosphorus nutrition on growth of potato genotypes with contrasting phosphorus efficiency. *African Crop Science Journal*, ;17(4)

Belachew B. Effect of nitrogen and phosphorus rates on growth, yield, yield components and quality of potato (Solanum tuberosum L.) at Dedo, South West Ethiopia, M.Sc. thesis. 2016;1-75.

Biswas, T. D. and Mukherjee, S. K. 1993. Text Book of Soil Science. (5th Eds.). Tata McGraw.

Biswajit Lenka, Sanjib Kumar Das. Effect of boron and zinc application on growth and productivity of potato (Solanum tuberosum) at alluvial soil (Entisols) of India, Indian *Journal of Agronomy* 2019;64(1):129-137

Berga, L., Gebremedhin, W., Terrisa. J., and Bereke, T. 1994a**:** Potato Agronomy Research. Proceedings of the Second National Horticultural Workshop of Ethiopia. Addis Ababa, 1-3 December 1992. Institute of Agricultural Research and Food and Agriculture Organization, Addis Ababa, Ethiopia.

Bouyoucos, G. J. (1927). The hydrometer as a new method for the mechanical analysis of soils. *Soil Sci.* **23:** 343-353.

Chaverri B.A.; Bornemisza E.; Banco Nacional de Costa Rica, San Jose. (1977) Phosphorus-zinc interactions in potato (Solanum tuberosum L.) in the Pacayas area [Costa Rica]. *Agronomia Costarricense, 1*, 83-92(2).

Christensen, N. W. and Jackson, T. L. (1981). Potention for phosphorus toxicity in zinc stressed corn and potato. *Soil Science Society of America Journal, 45*(5), 904–909.

Das, R.C. and Jena, M. K. (1973). Studies on effect of soil application of molybdenum, boron and paper mill sludge on the post-harvest qualities of potato tubers (*Solanum tuberosum* L.). *Madras Agricultural Journal* **60:** 1,026–1,029.

Divis, J. and Barta, J. (2001). Influence of the seed-tuber size on yield and yield parameters in potatoes. *Rostlinna Vyroba.* **47(6):** 271-275.

Dwivedi, G. k. and Dwivedi, M. (1992). Efficiency of different modes of application of copper, zinc and boron to potato. *Ann. Agril. Res*. **13(1):**1-6.

Efkar, A, Jan,N., Kharttak, S.G., khattak M. J. and Ahmad E. (1995). Potato yield as affected by boron fertilizer mixing with and without farmyard manure. Sarhad Journal of Agricultural Pakistan, 11 (6), 725-728.

Firew, G., Nigussie, D., & Wassu, M. (2016). Response of potato (*Solanum Tuberosum* L.) to the application of mineral nitrogen and phosphorus fertilizers under irrigation in Dire Dawa, Eastern Ethiopia. Journal of Natural Sciences Research, 6. 19–37.

FAOSTAT (FAO, Statistics Division). (2018). Statistical Database. Food and Agricultural Organization of the United Nations, Rome, Italy.

Gargantini, R., Leite, N., Hangria, L. S. and Venturini, W. R. (1970). Effect of micronutrient on yield and type of tuber potatoes grown in alluvial soils in the Paraiba Valley. *Brangantia.* 29(1):1-10. [Cited from field crop abst. 25(2) :317,1972].

Gelaye Y, Ademe D, Alemayehu M (2022) Effect of Phosphorus and Potassium Fertilizer Rates on Growth and Yield of Potato (*Solanum Tuberosum L.*), Northwestern Ethiopia. J Hortic. 8:538.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). *Int. Rice Res. Inst. A Willey Int. Sci*., pp. 203-211.

Glass, A., Britto, D., Kaiser, B., Kinghorn, J., Kronzucker, H., Kumar, A., Okamoto, M., Rawat, S., Siddiqi, M., Unkles, S., and Vidmar, J. (2002). The regulation of nitrate and ammonium transport systems in plants. *Journal of Experimental Botany;* (**53)**: 855-864.

Gray, D. and Hughes, J.C. 1978. Tuber Quality. In: The potato Crop: The Scientific Basis for improvement (P.M. Harris, Ed.).

Grewal, J. S. and Trehan, S.P. (1980). Micronutrient requirement of potatoes. J. *Indian Soil Sci.* **37(2):**258-262.

Gupta, U. C. and Sanderson, J.B. (1993). Effect of sulphar, calcium and boron on tissue nutrient and potato yield. *J. Plant Res.Station Agric Canada*. **16(6):**1013-1023.

Hanley, F., Jarvis, R. H., & Ridgman, W. J. 1965. The effects of fertilizers on the bulking of Majestic potatoes. *The Journal of Agricultural Science, 65*(02), 159-169

Hazra, G. C. (2012). Micronutrient research in West Bengal. *Mohanpur: Bidhan Chandra Krishi Viswavidyalaya*, 1-73.

Haynes, K. G., Yencho, G. C., Clough, M. E., Henninger, M. R., & Sterrett, S. B. (2012). Genetic Variation for Potato Tuber Micronutrient Content and Implications for Biofortification of Potatoes to Reduce Micronutrient Malnutrition. *American Journal of Potato Research*, 89(3), 192–198.

Hopkins B, Hopkins BG, Horneck DA, Macguidwin AE (2014). Improving PUE through Potato Rhizosphere Modification and Extension. *American Journal of Potato Research 91*(2):161-174

Hoque(1994). Potato can be used in numerous ways, such as, boiled, baked and dehydrated potatoes, canned potatoes and as starch for culinary purposes. *Indian Council of Agric. Res*., New Delhi. Pp. 24-25.

Ierna, A., Pellegrino, A., & Malvuccio, A. (2017, December). Effects of micronutrient fertilization on the overall quality of raw and minimally processed potatoes. *Postharvest Biology and Technology, 134,* 38–44

Islam, J., *et al*., (2020). Evaluation of Tuber Yield and Marketable Quality of Newly Developed Thirty-Two Potato Varieties Grown in Three Different Ecological Zones in South Korea, *Agriculture,* 10, 327

Iwama, K. (2008). Physiology of the potato: New insights into root system and repercussions for crop management. *Potato Res., 51, 333.*

Jackson, M. L. (1973). Soil Chemical analysis. Prentice Hall. Inc. N. J., USA. p. 46.

Jenkins, P. D., & ALI, H. (1999). Growth of potato cultivars in response to application of phosphate fertilizer. *Annals of Applied Biology*, 135(1), 431–438

Kabir, Z., K. Hossain, M. A., Khan, I. and Islam, M.S. (1994). Effect of different fertilizers on the yield of potato.1st National Workshop on Tuber crops. TCRC, BARI, Joydebpur, Gazipur. pp. 81-90.

Keeps, M.S. (1979). Production of field crops. 6th Edn. Tata Mc-Graw Hill Publishing Co. Ltd., New Delhi. p. 369.

Kirynkhin, V.P and Bezzubtseba, T.T., 1980. Application of trace elements to potato. Kartofel, *Ovoshch no. 4*: 16. [Cited from Potato Abstr., 7(1):45, 1982].

Khurana, S.C., and Rana, M.K., (2000). Potato: Olericulture in India, 1st edn, Kalyani Publishers, New Delhi.

Lenka, B., RK, D., & SK, D. (2020, May 1). Nutrient use effeciency, yield attributes and comparative economics of potato crop (Solanum tuberosum L.) in response to zinc and boron nutrition in entisols of India. International Journal of Chemical Studies, 8(3), 10–17.

Lozek, O. and Fecenko, J. (1993).Effect of foliar application of manganese, boron and sodium humate on the potato production. Department of Agro-chemistry and plant Nutrition. University of Agriculture, Trieda Slovakia. [Cited from Potato. **9(5):**910913, 1994].

Mahmud, K., Ahmad, I., and Ayub, M. (2003). Effect of nitrogen and phosphorus on the fodder yield and quality of two sorghum cultivars (*Sorghum bicolor* L.): *International Journal of Agriculture* **5**: 61-63.

McCollum, R. E. (1978). Analysis of Potato Growth under Differing P Regimes. I. Tuber Yields and Allocation of Dry Matter and P 1. *Agronomy Journal*, 70(1), 51–57.

Medevedev, A.G.; Chertko, N.K.; Lipskaya G.A.; Ivanov, N.P.; et al. (1981). Effect of trace elements on yield and growth of potatoes grow on reclaimed dornovo-podologic gray soils. *Agrokhimiya.* **3:**101-114.

Mengel, K. and E. Kirkby. (1987). Principles of plant nutrition, 4th ed. International Potash Institute. Bern.

Mica, B. (1975). Influence of boron, manganese and zinc on the yield and principal compounds of potato tubers. Potato Res. **26(4):**383-391.

Misgina NA (2016). Effect of P and potassium fertilizer rates on yield and yield component of potato (*Solanum tuberosum* L.) at K/Awlaelo, Tigray, Ethiopia. *Food Science and Quality Management 48*: 60-69.

Mikkelsen R. (2014). Phosphorous management for potatoes. Better Crops Plant Food 99(4): 10-11.

Miller, R.W. and Donanue R. L. (1995) .Soils in our environment. (7thed.). Prentice Hall, Englewood Cliff. 261- 281.

MOA. (Ministry of Agriculture). (2021). Hand Book of Agricultural Statistics, Market Monitoring and Information System, Ministry of Agriculture (MOA), Govt. People's Repub. Bangladesh. p. 367.

Mohammad Ali Muthanna, Anil K. Singh, A. Tiwari, V.K. Jain and Padhi, M. 2017. Effect of Boron and Sulphur Application on Plant Growth and Yield Attributes of Potato (Solanum tuberosum L.). *Int.J.Curr.Microbiol.App.Sci.* 6(10): 399-404.

Montemurro, F., Convertini, G., and Ferri, D. (2007). Nitrogen application in winter wheat grown in Mediterranean conditions: Effects on nitrogen uptake, utilization efficiency and soil nitrogen deficit. *Journal of Plant Nutrition* **30:** 1681-1703.

Mugo, J. N., Karanja, N. N., Gachene, C. K., Dittert, K., Gitari, H. I., & Schulte-Geldermann, E. (2021, January 1). Response of potato crop to selected nutrients in central and eastern highlands of Kenya. *Cogent Food & Agriculture*, 7(1).

Mulubrhan Haile, (2004). The Effects of Nitrogen, Phosphorus, and Potassium Fertilization on the Yield and Yield Components of Potato (*Solanum tuberosum* L.) Grown on Vertisol of 56 Mekelle Area, Ethiopia. MSc Thesis submitted to the Faculty of the Department of Plant Science, School of Graduate Studies, and Alemaya University, Ethiopia. 83.

Nyiraneza, J., Bizimungu, B., Messiga, A., Fuller, K., Fillmore, S. A., & Jiang, Y. (2017). Potato Yield and Phosphorus Use Efficiency of Two New Potato Cultivars in New Brunswick, Canada. *Canadian Journal of Plant Science*.

Öztürk, E., Kavurmacı, Z., Kara, K. et al. The Effects of Different Nitrogen and Phosphorus Rates on Some Quality Traits of Potato. Potato Res. 53, 309–312 (2010)

Omer, F. A., & Hafez and Foda, S. (1982). Efficiency of potassium levels and boron concentration on the production of potatoes. *Res. Bull. Agril. Ain Shams Univer. Egypt*, 15p.

Olsen, S.R., Cole, C.V., Watanabe, F. S. and Dean, L. A. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S. Dept. Agr. Cire. p.939**.**

Page, A. L., Miller, R. H. and Keeney, D. R. (1982). Methods of soil analysis, Part 2. Amer. Soc. Agron. Madi. USA. Pp. 539- 622

Palkovics, M. and Gyori, D. (1984). Trials of boron fertilizers on rusty brown forest soil in potatoes. Novenytermeler, **33(3):**265-273. [Cited from Potato Abst. **13(3):**252, 1986].

Peixoto, J. R., Garcia C. A. P. and Martins, J. F. (1996). Yield of potatoes cv. Achat as function of rates of NPK and B. *Horticultura Brasileira, Brazil*. **14(2):** 232235.[cited from Field Crop Abst. **9(5):** 826,1997].

Perrenoud, S. 1983. Potato: Fertilizer for yield and quality. IPI Bull. No. 8. International Potash Institute, Berne, Switzerland.

Piper, C.S. 1942. Soil and plant analysis. Interscience, New York, p. 221-222.

Porter, G. A., Morrow, L.S. and Murphy, H.J. (1986). Boron fertilization of Katahdin potatoes under acid soil conditions. *Amer. potato J.* **63(8):**448.

Powon, P. 2005. Effects of inorganic fertilizers and farm yard manure on growth, yield and tuber quality of potato *(Solanum tuberosum* L.). An Msc Thesis Presented to school of graduate study Egerton University; pp: 59

Prasad, R., Kumar, D., Shivay, Y.S. and Rana, D.S. (2014). Boron in Indian agriculture review. *Indian Journal of Agronomy*. **4(5):** pp.456-459.

Pregno, L.M. and Arour, J.D. (1992). Boron deficiency and toxicity in potato cv. Sebago on an oxisol of the Atherton, North Queensland. *Aus. J. Exp. Agric*. **32(2):**251 253.

Rai, Kumar, Pathak, & Kumar Patel. (2021). Effect of zinc and boron on potato yield and quality, nutrient uptake and soil health. *The Pharma Innovation Journal,* 10(11).

Qadri, R. , Khan, I. , Jahangir, M. , Ashraf, U. , Samin, G. , Anwer, A. , Adnan, M. and Bashir, M. (2015) Phosphorous and Foliar Applied Nitrogen Improved Productivity and Quality of Potato. *American Journal of Plant Sciences, 6, 144-149.*

Qiu, Y., Fall, T., Su, Z., Bortolozo, F., Mussoline, W., England, G., Dinkins, D., Morgan, K., Clark, M., & Liu, G. (2022, March 27). Effect of Phosphorus Fertilization on Yield of Chipping Potato Grown on High Legacy Phosphorus Soil. *Agronomy*, *12*(4), 812.

Quaggio, J. A and Ramos,V. J. (1986). Potato response to lime and boron application. Revista Brasileira De Ciencia Dosolo, **10(3):**247-251.[Cited from potato Abst.,**6(1):** 187-1986].

Rasp, H. (1985). The effect of added trace elements in a 12-year crop rotation Land weitschaffiche Foresckung. **38(4):**345-403[Cited from potato Abst**.,6(1):**203,1986]

Rai, Kumar, Pathak, & Kumar Patel. (2021). Effect of zinc and boron on potato yield and quality, nutrient uptake and soil health. The Pharma Innovation Journal, 10(11)

Rending, V. V., and Taylor, H. M. (1989). Principles of soil-plant interrelationships. McGraw-Hill Publishing Company.

Rosen, C. J. and Bierman, P. M. (2008). Potato yield and tuber set as affected by phosphorus fertilization. *American J. Potato Res*. **85(2).** 110-120.

Sanderson, J. B. and Gupta, U. C. (1990). Copper and zinc nutrition of Russet Burbank potatoes grown on Prince Edward Island, Canada. J. *Plant Sci.* **70(1):** 357-362.

Sanderson, J., MacLeod, J., Douglas, B., Coffin, R., & Bruulsema, T. (2003). Phosphorus research on potato in pei. *Acta Horticulturae, 619,* 409–417

Sapatyi, S. E and Shkvaruk, R. N. (1973). Effect of trace elements on yield and absorbing capacity of potato plant.Nauchnye Trudy Ukrainskoi Selskokhozyaistvennoi Akademii no.144, 82-89. [Cited from *Indian J.Plant Sci.* **5(4):**485, 1975]

Sarkar, N. S. I., Zaman, S., Islam, M. S. and Mannaf, M. A. (1996). Effect of fertilizer alone and in combination with cow dung on the growth and yield of potato. *Bangladesh J.Agril.Sci.* **21(1):**275-282.

Sarkar, S., Banerjee, H., Ray, K., & Ghosh, D. (2018). Boron fertilization effects in processing grade potato on an Inceptisol of West Bengal, India. *Journal of Plant Nutrition*, *41(*11), 1456–1470.

Sathya, S., Pitchai, G.M. and Indirani, R. (2009). Boron nutrition of crops in relation to yield and quality – A review. *Agricultura Reviews.* **30(2):** 139–144.

Schoenemann, J.A. (1977). Grading, packaging and Marketing potatoes, In: Potatoes production, storing processing, (Ed.). Smith. 2nd Edition. The AVI publishing company Inc., West port, pp. 470-505.

Sebnie, W., Esubalew, T. & Mengesha, M. Response of potato (*Solanum tuberosum* L.) to nitrogen and phosphorus fertilizers at Sekota and Lasta districts of Eastern Amhara, Ethiopia. Environ Syst Res 10, 11 (2021).

Setu, H., and Mitiku, T. (2020). Response of potato to nitrogen and phosphorous fertilizers at Assosa, western Ethiopia, *Agronomy Journal*, *112*(2).

Somerfield, T. G., & Knutson, K. W. 1965. Effects of nitrogen and phosphorus on the growth and development of Russet Burbank potatoes grown in southeastern Idaho. *American Potato Journal*, *42*(12), 351-360.

Soltanpour, P. N., & Cole, C. V. (1978, October). Ionic balance and growth of potatoes as affected by N plus P fertilization. *American Potato Journal, 55*(10), 549–560

Sharma, U. C., and Arora, B. R. (1987). Effect of nitrogen, phosphorus and potassium application on yield of potato tubers (*Solanum tuberosum* L.). *The Journal of Agricultural Science. 108*(02), 321-329.

Singh, S., Sharma, M., Reddy, K., & Venkatesh, T. (2018, March 8). Integrated application of boron and sulphur to improve quality and economic yield in potato. *Journal of Environmental Biology*, *39*(2), 204–210.

Sommerfeld, T., and Knutson, K. (1965). Effects of nitrogen and phosphorus on the growth and development of Russet Burbank Potatoes grown in the Southeastern *Idaho. American Potato Journal;* **42**: 351-360.

Stark, J.C. and S.L. Love (*eds*.). (2003). Potato Production Systems. University of Idaho Agricultural Communications. Moscow, ID.

Taghavi, T., Babalar, M., Ebadi, A., Ebrahimzadeh, H., and Asgari, M. 2004. Effects of nitrate to ammonium ratio on yield and nitrogen metabolism of strawberry. *International. Journal of Agriculture and Biology* **6:** 994-997

Tang, J., Wang, J., Wang, E., Yu, Q., Yin, H., He, D., & Pan, X. (2018, June). Identifying key meteorological factors to yield variation of potato and the optimal planting date in the agro-pastoral ecotone in North China. *Agricultural and Forest Meteorology*, 256–257, 283–291.

Trehan, S. P. and Grewal, J.S. (1981). Comparative efficiency of methods of application of zinc to potato. *Indian J. Agril. Sci.* **51(4):**240-243.

Tisdale, S. L. and Nelson, W. L .1995. Soil fertility and fertilizers. 3rded. NY: Macmillan, pp. 196–208.under tropical condition. In: Potato seed production for Tropical Africa, (eds.) Nganga, S. and F. Shielder, CIP, Lima, and Peru. 13-16.

Tisdsale, S. L., Nelson, W. L. and Beaton, J. D. (1984). Soil Fertility and Fertilizer (4^{th} ed.) Macmillan Pub. Comp. N Y.p.52.

Upadhayay, N. C. and Grewal J. S. (1983). Effect of micronutrient fertilization through commercial mixtures on potato yield. *Bangladesh Hort.* 11(1):5-9.

Veereshkumar Shirur, Channakeshava S and ST Bhairappanavar. Effect of different levels of gypsum and boron on yield, nutrient content and uptake by potato (*Solanum tuberosum L.*). *J Pharmacogn Phytochem* 2021;10(1):1163-1169.

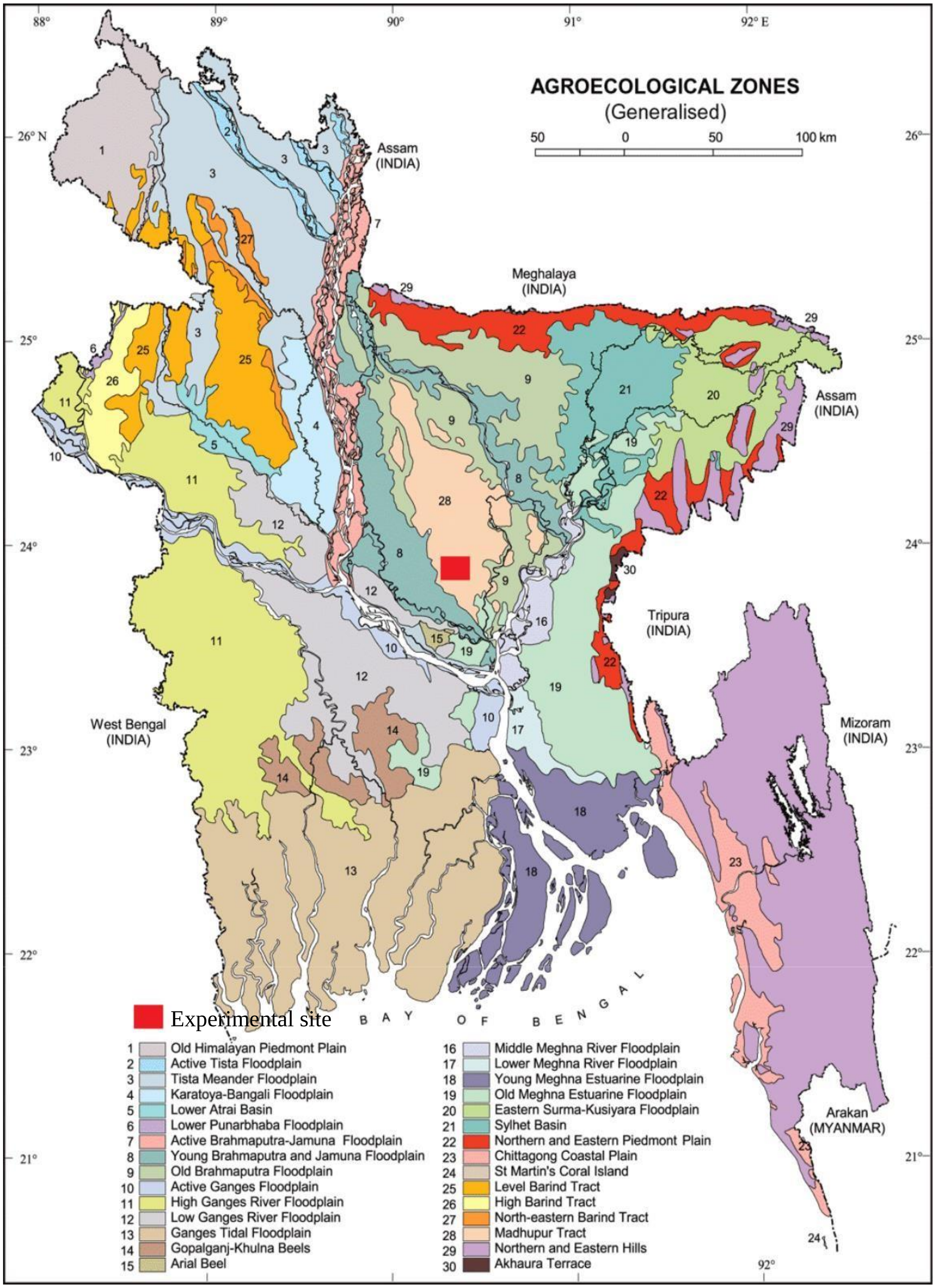
Wijnholds, K.H.; Berg, W. van den 1996: Crop rotation experiment AGM 600. Effect of crop rotation organic matter and nitrogen supply on the production of potatoes, sugarbeet, spring wheat and oats on reclaimed moor. *Publicatie Proefstation voor de Akkerbouw en Ade akkerbouw en de Groenteteelt in de Vollegrond Lelystad (81A)*: 45-49

Zewide, I., Mohammed, A., and Tulu Tades, S. (2016). Potato (*Solanum tuberosum* L.) Growth and Tuber Quality, Soil Nitrogen and Phosphorus Content as Affected by Different Rates of Nitrogen and Phosphorus at Masha District in Southwestern Ethiopia. *International Journal of Agricultural Research*, *11*(3), 95–104.

Zelalem, A., Takalign, T. and Nigussie, D. (2009) .Response of potato (*Solanum tuberosum* L.) to different rate of nitrogen and phosphorus fertilization on vertisols at Debre Birhan, in the central highlands of Ethiopia. *African journal of plant science*. **3**(2). 16-24.

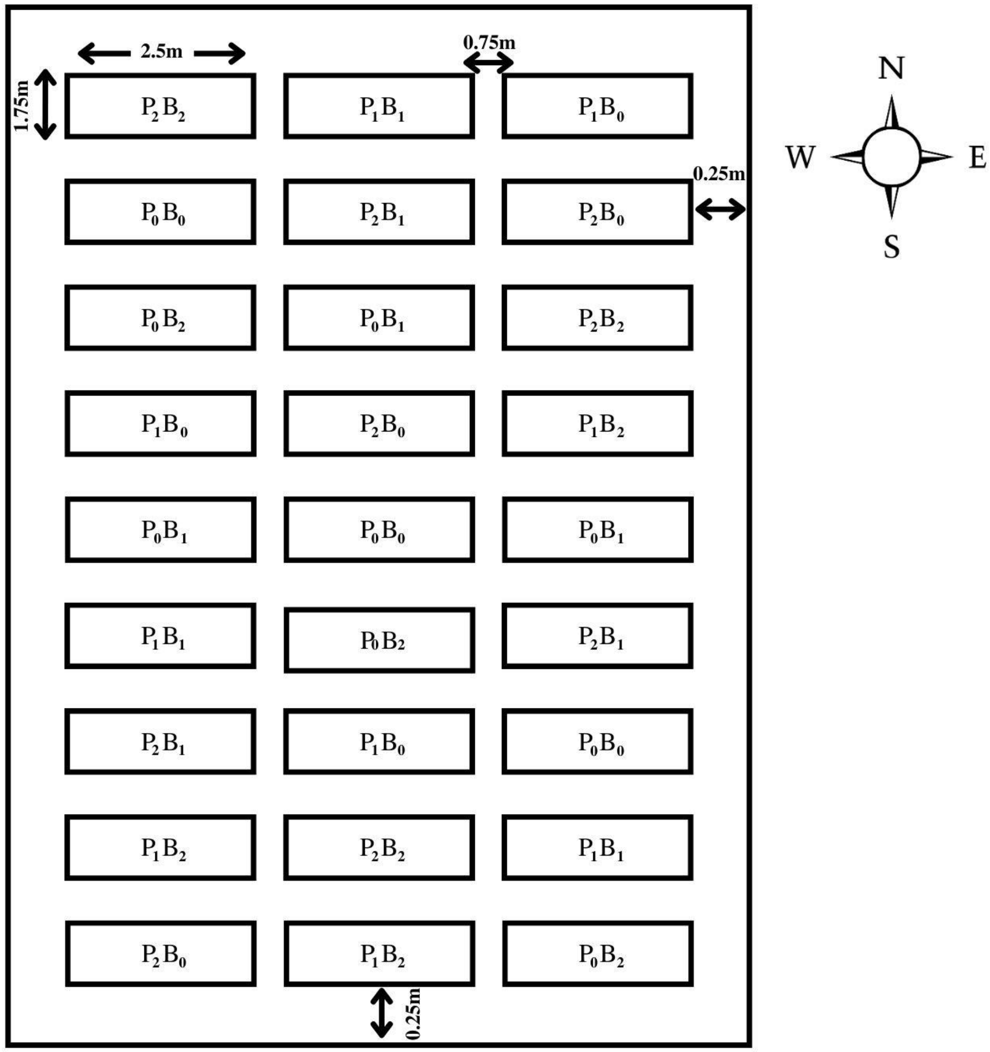
CHAPTER VII
APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location (AEZ-28)



APPENDIX II. Layout of the experiment field

Plot size: 2.5 m × 1.75 m (4.4 m^2)
Plot to plot distance: 0.50 m
Block to Block distance: 0.75 m



APPENDIX III. Monthly average of air temperature, relative humidity and total rainfall of the experimental site during the period from November, 2021 to February, 2022.

Months	Air Temperature (°C)		Humidity	Total Rainfall
	Maximum	Minimum		
November	32	14	73	66
December	31	12	76	5
January	28	9	75	12
February	32	10	63	30

Source: Bangladesh Meteorological Dept. (Climate & weather division) Agargoan, Dhaka-1207

APPENDIX IV: Morphological Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

Morphological Feature	Characteristics
Location	Experimental Field, SAU, Dhaka-1207
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land Type	High land
Soil Series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

APPENDIX V: Physical and properties of the initial soil chemical

Characteristics	Value
Partical size analysis	
%Sand	51
%Silt	43
%Clay	6
Textural class	Sandy loam Soil
Organic carbon	0.663
Organic matter(%)	1.14
Soil pH	6.1
Available Phosphorous(ppm)	23.16
Available Sulphur	6.59

Source**:** Initial Soil sample was analyzed in laboratory of soil science department, SAU**.**

APPENDIX VI. Analysis of variance (mean square) of the data on plant height of potatoes as influenced by phosphorous and boron on different days after planting.

Sources of variations	Degrees of freedom	Mean square of Plant height (cm)	
		30 DAP	60 DAP
Replication	2	0.131	0.009
Factor A	2	149.605**	124.380**
Factor B	2	67.260**	30.994**
AB	4	22.259**	4.978**
Error	16	0.093	0.096

NS = Non significant * = 5% level of significance ** = 1% level of significance

APPENDIX VII. Analysis of variance (mean square) of the data on **the** number of stems hill^{-1} of potatoes as influenced by phosphorous and boron on different days after planting.

Sources of variations	Degrees of freedom	Mean square of the number of stems hill^{-1}	
		30 DAP	60 DAP
Replication	2	0.09148	0.00778
Factor A	2	3.65481**	3.40111**
Factor B	2	3.88593**	5.70111**
AB	4	0.34148**	0.06722*
Error	16	0.03440	0.02236

NS = Non significant * = 5% level of significance ** = 1% level of significance

APPENDIX VIII. Analysis of variance (mean square) of the data on number of leaves hill^{-1} of potatoes as influenced by phosphorous and boron on different days after planting.

Sources of variations	Degrees of freedom	Mean square of the number of leaves hill^{-1}	
		30 DAP	60 DAP
Replication	2	0.629	32.70
Factor A	2	153.551**	2014.78**
Factor B	2	142.071**	1404.92**
AB	4	2.502**	135.40**
Error	16	0.171	24.77

NS = Non significant * = 5% level of significance ** = 1% level of significance

APPENDIX IX. Analysis of variance (mean square) of the data on the yield parameters and yield of potatoes as influenced by phosphorous and boron.

Sources of variations	Degrees of freedom	Mean square of Yield contributing parameters				
		Number of tuber hill^{-1}	Tuber Weight hill^{-1} (gm)	Tuber yield plot^{-1} (kg)	Tuber yield (t ha^{-1})	Marketable yield (t ha^{-1})
Replication	2	0.5444	97.2	0.0619	0.387	0.909
Factor A	2	7.10333**	80956.1**	65.6450**	412.051**	410.723**
Factor B	2	3.64778**	48340.4**	27.6748**	173.688**	185.473**
AB	4	0.51778**	4642.8**	1.1967**	7.511**	15.795**
Error	16	0.06528	106.2	0.0777	0.488	0.436

NS = Non significant * = 5% level of significance ** = 1% level of significance

APPENDIX X. Analysis of variance (mean square) of the data on **the** size of potato tuber as influenced by phosphorous and boron

Sources of variations	Degrees of freedom	Mean square of size of potato tuber	
		Length of tuber	Width of tuber
Replication	2	1.0033	0.6115
Factor A	2	13.6078**	11.6137**
Factor B	2	NS	2.1137**
AB	4	NS	3.9737**
Error	16	0.6371	0.4090

NS = Non significant * = 5% level of significance ** = 1% level of significance

APPENDIX XI: Analysis of variance (mean square) of the data on **the** effect of phosphorous and boron fertilizer on soil pH, available phosphorus, and available sulphur concentrations in postharvest soil in the potato field.

Sources of variations	Degrees of freedom	Mean square of soil pH, organic matter, available phosphorus, and available sulphur concentrations in postharvest soil			
		Soil pH	Organic matter (%)	Available Phosphorous (ppm)	Available Sulphur (ppm)
Replication	2	0.01	1.693	1.945	0.076
Factor A	2	0.04111**	NS	85.327**	114.479**
Factor B	2	0.02333**	NS	218.785**	0.480**
AB	4	0.01278*	NS	88.242**	2.388**
Error	16	0.00375	3.297	2.351	0.085

NS = Non significant * = 5% level of significance ** = 1% level of significance

SOME PICTORIAL VIEWS OF RESEARCH WORK

Plate 1: General view of the experimental field during land preparation

Plate 2. General view of the experimental field during seed sowing

Plate 3: General view of the experimental plot during the emergence of plant

Plate 4: General view of the experiment plot after weeding

Plate 5: General view of the experiment plot during earthing up

Plate 6: General view of spraying pesticide for plant protection

Plate 7. General view of the experimental field

Plate 8. General view of the experimental field during the vegetative condition

Plate 9. General view of observation of Supervisor sir in the experimental field

Plate 10. General view of the experiment field during harvesting of potato

Plate 11. General view of post-harvest soil analysis

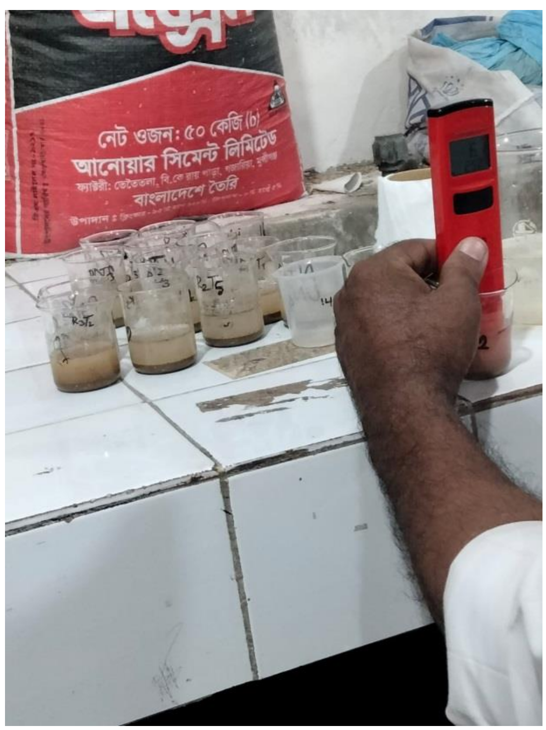


Plate 12. General view of post-harvest soil analysis

Plate 13. General view of post-harvest soil analysis

Plate 14. General view of post-harvest soil analysis

Plate 15. General view of post-harvest soil analysis

Plate 16. General view of post-harvest soil analysis

Plate 17. General view of post-harvest soil analysis