EFFECT OF BLENDED NPS AND BORON FERTILIZER RATES ON GROWTH, YIELD AND QUALITY OF CARROT (*Daucus carota* L.) AT DEBRE BERHAN, CENTRAL HIGHLAND OF ETHIOPIA

MSc. Thesis

Nardos Ayalew Gezmu

May 2024

Debre Berhan, Ethiopia

EFFECT OF BLENDED NPS AND BORON FERTILIZER RATES ON GROWTH, YIELD AND QUALITY OF CARROT (*Daucus carota* L.) At DEBRE BERHAN, CENTRAL HIGHLAND OF ETHIOPIA

A Thesis Submitted to the Department of Horticulture

College of Agriculture and Natural Resource Sciences, College of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

Nardos Ayalew

Major Advisor: Bizuayehu Desta (Ph.D.)

Co-Advisor: Fresew Belete (Ph.D.)

May 2024

Debre Berhan, Ethiopia

COLLEGE OF GRADUATE STUDIES

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – I

This is to certify that the thesis entitled: **Effect of Blended NPS and Boron Fertilizer Rates on Growth, Yield and Quality of Carrot (*Daucus carota* L.) at Debre Berhan, Central Highland of Ethiopia** submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Horticulture of the Graduate Program in department of horticulture, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Nardos Ayalew, DBU1400521, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

__________________________ ___________________ ___________________

Name of Major Advisor Signature Date

Or

__________________________ ___________________ ___________________

Name of Co-Advisor Signature Date

COLLEGE OF GRADUATE STUDIES

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – II

We, the undersigned members of the board of the examiners of the final open defense by Nardos Ayalew have read and evaluated her thesis entitled: Effect of Blended NPS and Boron Fertilizer Rates on Growth, Yield and Quality of Carrot (*Daucus carota* L.) at Debre Berhan, Central Highland of Ethiopia, and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Horticulture.

______________________	____________________	____________________
Name of the Chairman	Signature	Date
______________________	____________________	____________________
Name of Major Advisor	Signature	Date
______________________	____________________	____________________
Name of Internal Examiner	Signature	Date
______________________	____________________	____________________
Name of External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate’s major department.

ACKNOWLEDGEMENT

First and foremost, praises and thanks to the Almighty God who gave me the patience, health and endurance to bear the rigorous academic life and research work and also for his blessings throughout my entire life to the victory and completion of this thesis with his Mother Saint Virgin Mary. Next, I would like to express my deepest gratitude and appreciation to my major advisor Dr. Bizuayehu Desta and co-advisor Dr. Fresew Belete for their invaluable patience and feedback, giving me time from their tight schedule, corrections, assistance, professional guidance, encouragement and constructive comments starting from the write-up of the proposal to the preparation of the thesis manuscript.

I'm extremely grateful to Debre Berhan University, College of Agriculture and Natural Resource Sciences and Horticulture Department for permission of land to conduct the field experiment and for their moral and material support. I would like to extend my sincere thanks to the Horticulture and Plant Science Laboratory’s assistances for the all-round support that helped me during field and laboratory work. Many thanks also go to Debre Berhan Agricultural Research Center Soil Laboratory for helping me with soil analysis.

I had the pleasure to express my heartful thanks to Abrham Kefelew, Hirut Seyoum, Ermiyas Bekele, Shibere Debebe, Workeye H/Meskele, Kidist Adenew and Habtu Mamuye for their Moral support, Inspiration, Advice and suggestions, enthusiasm, material and energy support throughout the entire research work.

Last, but not least, Words cannot express my gratitude to my beloved family my father Ayalew Gezmu, my mother Almeshet Tafes, my brothers Ermiyas Ayalew and Dagim Ayalew, my sister Eldana Mikiyas with her mother Tenagen Tafes and my aunt Tirunsh Gezmu with her husband Getachew Abebe for their belief on me has kept my spirits and motivation high during this study and also their caring, emotional and financial support. I would like to extend my genuine gratitude to Netsanet Gebremedhin for his patience and support throughout the research time. Finally, I am also grateful to all those who directly or indirectly helped and encouraged me in all my journey and work

DEDICATION

This thesis is dedicated to my beloved family for giving me their love that can’t replaced with anything, prayers, precious time, energy, money and also for their complete and utter dedication to my success in my life

STATEMENT OF THE AUTHOR

I, Nardos Ayalew, hereby declare that, this thesis is my genuine work, and that all sources of materials used for this thesis have been profoundly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for Master of Science (MSc) at Debre Berhan University and it is deposited at the University library to be made available for users under the rule of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the College of Graduate Studies when in his/her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

Name: NARDOS AYALEW GEZMU

Signature: _______________

Place: Debre Berhan University.

Date of Submission: May, 2024

BIOGRAPHICAL SKETCH

The author, Miss. Nardos Ayalew Gezmu was born from her father Mr. Ayalew Gezmu and her mother Mrs. Alemeshet Tafes at Debre Berhan town North Shewa Zone, Amhara National Regional State, Ethiopia on November 14, 1998. She attended her elementary education at Biruhe Tesfa Primery School from 2005-2012 and she attended her secondary and preparatory education at Debre Berhan General School from 2013- 2014 and Hailemariam Mamo Preparatory School from 2015-2016. Then, she joined Arba Minch University in 2017 after one academic year transferred to Debre Berhan University in September 2018 and graduated with BSC degree in Horticulture in January 2021.

In February, 2022, she joined the college of Graduate Studies of Debre Berhan University to pursue her MSc. degree in Horticulture.

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
DMRT	Duncan's Multiple Range Test
EC	Electrical Conductivity
EIA	Ethiopian Investment Agency
ETB	Ethiopian's Birr
EthioSIS	Ethiopian Soil Information System
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization Statistics
FDRE	Federal Democratic Republic of Ethiopia
M. a. s. l	meter above sea level
MoANR	Ministry of Agriculture and Natural Resource
NPS	Nitrogen, Phosphorus and Sulfur
RCBD	Randomized Complete Block Design
RNA	Ribonucleic Acid
SAS	Statistical Analysis System
TSS	Total Soluble Solid
USSLS	United States Salinity Laboratory Staff

TABLE OF CONTENTS

Contents **page**

TABLE OF CONTENTS(continuied)

LIST OF TABLES

Table **page**

LIST OF FIGURE

LIST OF TABLES IN THE APPENDIX

Appendix Table **Page**

EFFECT OF BLENDED NPS AND BORON FERTILIZER RATES ON GROWTH, YIELD AND QUALITY OF CARROT (*Daucus carota* L.)AT DEBRE BERHAN, CENTRAL

HIGHLAND OF ETHIOPIA

By: Nardos Ayalew

Major Advisor: Bizuayehu Desta (PhD)

Co-Advisor: Fresew Belete (PhD)

ABSTRACT

Carrot (Daucus carota L.*) is an important root vegetable cultivated widely in the world as well as in Ethiopia in particular. However, the total root yield is low at the international, national and regional levels as compared to its potential, due to various factors including lack of improved varieties, low soil fertility, inappropriate application rates and type of fertilizers, lack of enhanced agronomic and cultural practices, occurrence of diseases and insect pests and lack of improved post-harvest technologies. Among these, inappropriate application of macro and micronutrient fertilizers is the bottleneck of agronomic practices that caused tremendous yield reduction. Therefore, a field experiment was conducted at demonstration and research* site of *Debre Berhan University during the main cropping season of 2022/23 to evaluate the effects of different rates of blended NPS and boron fertilizers on growth, yield, and quality of carrot. The treatments consisted of factorial combinations of four rates of NPS fertilizer (0, 75, 150 and 225 kg ha^{-1}) and four levels of B (0, 250, 500 and 750ppm). The experiment was laid down in a randomized complete block design with three replications using the '*Nantes*' carrot variety as a test crop. Accordingly, the combined application of 150 kg ha^{-1} of NPS and 500ppm boron application rates resulted in the widest root diameter (2.45cm), highest root dry weight (19.34g), highest marketable root yield (56.28 t ha^{-1}), highest total root yield (58.68 t ha^{-1}) and highest dry matter content (45.7%). In addition, this treatment resulted in the highest net benefit (Birr 1248724 ha^{-1}) with an acceptable marginal rate of return (1879.22 %).In conclusion, the combined application of NPS at 150 kg ha^{-1} and B at 500ppm rates could be recommended to increase the production of carrot in terms of yield and quality in the study area and other similar agro- ecologies. However, additional study is needed in different seasons and locations to give full recommendation since the study was conducted in a single season and location.*

Keywords: Root yield, Macro-nutrient, Micro-nutrient

1. INTRODUCTION

Carrot (*Daucus carota* L.) is a biennial herbaceous species of the Apiaceae family Carrot (Rubatzky *et al.*, 1999) and is globally ranked third in production among the root crops, after cassava and sweet potato. It originated in southwestern Asia in the Afghanistan region (Koley *et al.*, 2014), then spread over Europe, Asia and the Mediterranean area (Dalby, 1997). It is one of the major vegetable crops cultivated worldwide (FAOSTAT, 2015). It provides 17% of the total vitamin A consumption, making it the single major source of beta carotene among the vegetables (Arscott and Tanumihardjo, 2010). They also provide the major dietary fiber component of food and a range of micronutrients and antioxidant compounds (Augspole *et al.,* 2014). It also contains vitamin C, thiamin B and riboflavin B (Fritz, 2013). Carrot is used in salads, stews and soups with other vegetables. Besides being food, carrot is therapeutic as it enhances resistance against blood and eye diseases (Kumawat *et al.*, 2018). It is also useful to control ulcers, eczema, boil and is used in cosmetic preparations to fight wrinkles (Ageless, 2009).

In recent years, carrot's economic and nutritional value has gained worldwide acceptance including Ethiopia. The total world production of carrots was 42,233349.85 tons, from 1110834 hectares of land with an average productivity of 38.02 t ha^{-1} (FAOSTAT, 2022). Among the top ten carrot producers, China is the largest producer accounting for nearly 45% of world production 18,676442 tons (FAOSTAT, 2022). Following China, other major producing countries were the USA, Russia, UK and Northern Ireland, Turkey, Germany, Ukraine, Indonesia, Pakistan and France respectively. In Africa the total production of carrot was 2274323.92 tons, from 133061 hectares of land with an average productivity of 17.09 t ha^{-1} (FAOSTAT, 2022). Ethiopia has ranked number 74 in the world ranking its production has been expanding mainly due to increasing urbanization and the recognition of carrots as a source of income and nutrition (Getachew and Mohammed, 2012). In Ethiopia, the total production of carrot is 26,457.22 tons from 7,047 hectares of land with average productivity of 3.75 t ha^{-1} (FAOSTAT, 2022). Amhara National Regional State is also one of the potential areas for the production of carrot with a total production of 9,145.85 tons from 1,619.58 hectares of land and with average productivity of 5.65 t ha^{-1} (CSA, 2022), while the production of carrot in the country in general as well as the region is below the potential and other production opportunities. This low yield is mainly due to the faulty of nutrient application and type of fertilizer use, lack of recommended spacing, irrigation problems, and date of planting (Gerba *et al.*, 2018).

Several factors are responsible for the successful cultivation of high-quality roots. Among these the judicious application of fertilizers is one of the important factors. The application of NPS fertilizer plays an important role in increasing productivity of vegetables including carrot in terms of yield and quality attributes as well as improving soil fertility. Application of 150 kg^{-1}ha NPS was significantly improved vegetative growth of carrot and also has direct relationships with increased root yield by their pivotal roles on the enhancement of physiological activity (Isreal and Tamirat, 2023). The improvement in growth, yield and marketable root yield of carrot as well as root quality resulted due to NPS fertilizer application at 150 and 200 kg^{-1}ha (Mohammed, 2019).

In addition to N, P and S, micronutrients also play pivotal roles in maintaining the overall health and vitality of plants. They are involved in various physiological and biochemical processes, each contributing uniquely to plant health and productivity (Tariq, 2020). These trace elements, which are often present in small amounts, are indispensable for activating and assisting enzymes that drive vital metabolic reactions (Gomes *et al.*, 2020), Boron is one of those important micronutrients concerned in physiological processes like carbohydrate metabolism, translocation and development of cell wall and RNA metabolism (Siddiky *et al.*, 2007; Herrera-Rodriguez *et al.*, 2010). Foliar applications of boron increased the vegetative growth, biochemical constituents and yield productivity of different vegetable crops (Abou ELYazied and Mady, 2012; El-Dissoky and AbdelKadar, 2013; Salim *et al.*, 2019). Minerals, carotenes and vitamin C concentrations of carrot root are also improved by boron supply (Singh *et al.*, 2012).

Most of Ethiopian highland areas have a great potential for the production of carrot. Debre Berhan is one of a carrot producing area in North Shewa zone of Amhara region. Among income-generating and source of nutrition crops, carrot is one of the most important vegetable crops produced in Debre Berhan and its surroundings. As it is a short-duration crop that providing higher yields per unit area, carrot production can be a favorite profitable enterprise for most small-scale or resource-poor farmers (Ahmad *et al.*, 2005). Although its importance, great potential for production and high market demand, still not satisfy production and productivity of carrot in Ethiopia as well as in Debre Berhan. The low yield of carrot in the producing and study area is not an indication of low yielding potential of this crop, but the low yield may be attributed to a number of reasons, viz. the production is still limited in small scale, improper management practice, inappropriate applications and rate of macro and micro-nutrient are the major production constrains. Even though, micronutrients has got less emphasis in fertilizer management research as well as the production sector, they are to be necessarily taken up by the plants from soil or supplemented through foliar application for good growth and yield of crops and maximizing the efficient use of applied macronutrient.

Ethiopian soil lacks most of the soil macronutrients such as Nitrogen (N), Phosphorus (P), Sulfur (S) and micro (Cu, B and Zn) nutrients (Ethio-SIS, 2016). According to the atlas of soil fertility made by Ethio-SIS, seven soil nutrients (N, P, K, S, Zn, B and Cu) are found to be deficient in the soils of Amhara region (ATA, 2016). The government of Ethiopia introduced blended NPS fertilizer in 2013 (MOANR, 2013) for substituting DAP across the country. However, the yield still remains unchanged as expected even if the recommended rates of NPS fertilizers are applied, Carrot producers are not aware of the proper NPS fertilizer management including the application rate. Most of the farmers use the blanket recommendation at national level and sometimes they use their own judgment referring to the previous (DAP) fertilizer recommendation rate which was known to the farmers for a long time. These resulted in sub-optimal levels of NPS fertilizer (19% N, 38% P and 7% S) which contributed to the low yield and quality of the produce. In addition to this, farmers are not trained about the application and use of micronutrients and also the rate as well as the use of micronutrient in combination with NPS fertilizers for carrot was not determined in the study area. Due to those reason, there is a need to find out optimum and economic rates of NPS and B fertilizers for carrot production to achieve higher number of root yield for consumption and market at Debre Derhan also to fill the production gap.

1.1. Objectives

1.1.1. General Objective

- To evaluate the effects of different rates of blended NPS and B fertilizers on the growth, yield, and quality of carrot.

1.1.2. Specific Objectives

- ✓ To evaluate the effects of different rates of blended NPS on the growth, yield and quality of carrot.
- ✓ To evaluate the effects of different rates of B fertilizers on the growth, yield and quality of carrot.
- ✓ To evaluate the interaction effect of different rates of blended NPS and B fertilizers on the growth, yield and quality of carrot.
- ✓ To determine economically feasible rates of blended NPS and B fertilizer for carrot production in the study area.

2. LITERATURE REVIEW

2.1. The Carrot Crop

Carrot (*Daucus carota* L.) is a biennial herbaceous species of the Apiaceae family Carrot (Rubatzky *et al.,* 1999). The binomial nomenclature of carrot is derived from French, Greek and Latin words i.e. 'carotte', 'daukos' and 'carōta', respectively. The family Apiaceae contains 466 genera and 3820 species and is one of the largest families of seed plants, and the genus Daucus contains ca. 40 species (Plunkett *et al.,* 2018; Spooner, 2019). Carrot is a diploid species (2n=2x=18) with nine pairs of chromosomes, and an estimated genome size of 473 Mb (Arumuganathan and Earle, 1991). In addition to diploid species, a tetraploid (D. glochidiatus) and hexaploid (D. montanus) species have been reported (Spooner, 2019). Carrot is herbaceous, biennial plant with height of 0.3 and 0.6 m; roughly hairy with a solid stem. In the first growing season, it shows a rosette of leaves during the spring and summer, builds up the stout taproot to store large amounts of sugars and nutrients for the production of flowers and seeds in the second year (Elzer-Peters, 2014).

Tap root is thick, swollen and the color of the root is varied and includes orange, yellow, purple, red, and white (Simon *et al.,* 2008), having conical shape, although cylindrical and round cultivars are also available. Stem is furrowed, bristly-haired or compressed and the internodes are not distinct. The leaves are tri-pinnate, finely divided, stalked, lacy and overall triangular in shape. Inflorescence is white or pink and it is a compound umbel, 3-7cm in diameter, borne on a branched stalk with five petals and five ovaries that are hairy. Flowers are mainly bisexual but male flowers may be present in addition to bisexual flowers. The flowers may be often one to few dark purple sterile flowers present in the center of umbel. Once the flowers are pollinated, the umbel closes in on itself and dries out as the seeds mature (Stokes and Stokes, 1985). The fruit is oblong in shape that develops a schizocarp consisting of two mericarps; each mericarp is a true seed. Mature seeds are flattened on the commissural side that faced the septum of the ovary. The flattened side has five longitudinal ribs. Seeds also contain oil ducts and canals. Seeds vary somewhat in size, ranging from less than 500 to more than 1000 seeds per gram (Rubatsky *et al.*, 1999).

2.2. Use and Importance of Carrot

Carrot is widely cultivated since a long time in Ethiopia; but, it is often grown by small-scale farmers on a piece of land at their backyards mostly for own consumption. Carrot roots are used as vegetables for salads, soups and are also steamed or boiled in other vegetable dishes. The foliage of carrot is used as forage particularly feeding horses and cattle. Carrot ranks tenth in nutritional value among various fruits and vegetables (Acharya *et al.,* 2008). Its root is considered as one of the most delicious and luscious root and is highly nutritive. Besides food value, different parts of carrot can be used for different medicinal purposes due to its wide range of pharmacological effects. Carrot is an important source of phytonutrients including phenolics (Babic *et al.,* 1993), polyacetylenes (Hansen *et al.,* 2003; Kidmose *et al.,* 2004), β-carotene, ascorbic acid and tocopherol (Hashimoto and Nagayama, 2004). It is very helpful to maintain eye health and also serves as an antioxidant (Dias, 2014). Chemo protective compounds are the products of carrots that protect the body against many diseases of civilization (Bystricka *et al.,* 2015). Carrots contain almost no starch, about 1% protein, 7% carbohydrate, 0.2% fat, and 3% fiber (USDA, 2014).

The B vitamins including thiamin, riboflavin, niacin, pantothenic acid, folate, and vitamin B6 are found in carrots in appreciable quantities when compared with other commonly consumed vegetables (Arscott and Tanumihardjo, 2010). It is also a good source of dietary fiber and of the trace mineral molybdenum, rarely found in many vegetables. Molybdenum aids in metabolism of fats and carbohydrates and is important for absorption of iron. It is also a good source of magnesium and manganese.

Magnesium is needed for bone, protein, making new cells, activating B vitamins, relaxing nerves and muscles, clotting blood and energy production; secretion and functioning of insulin also require magnesiun (Bartletf *et al.,* 2008; Guerrera *et al.,* 2009; Kim *et al.,* 2010). Polyacetylenes rather than betacarotene or lutein was the bioactive components found in D. carota and could be useful in the development of new leukemic therapies (Ziani *et al.,* 2012). It also plays an important role in anti-inflammatory (Metzger *et al.,* 2008), wound healing (Patil *et al.,* 2012), diuretic (Stanic *et al.,* 1998), anti-ulcer (Nayeem *et al.,* 2010), muscle relaxant and lowering of blood pressure (Gilani *et al.,* 1994), memory improvement (Vasudevan *et al.,* 2010) and anti-fertility (Jansen and Wohlmuth, 2014).

2.3. Opportunities and Challenge of Carrot Production in Ethiopia

Ethiopia has favorable climate and edaphic conditions for the production of tropical, sub-tropical and temperate vegetables in the lowlands (<1500 meters above sea level), midlands (1500-2200) and highlands (>2200), respectively (FDRE, 2012). Carrots are produced in this wide range of agro-ecologies from the lowlands to the highlands of Ethiopia. It can be grown throughout the year, except in extremely cold areas or very hot regions (Joubert *et al.,* 1994; Rubatzky *et al.*, 1999). Besides, Ethiopia is also endowed with abundant surface irrigation water resources, coming from the country's twelve river basins, which are estimated to be in the order of 122 billion cubic meters per year (Kassa, 2015) and underground water potential is estimated to be 40 billion M^3 (Abiti, 2011). Further, the abundant labor, vast land and water resources give her an opportunity and facilitation for the production of different types of vegetable crops including carrots (Fekadu and Dandena, 2006).

Its proximity to Djibouti and Somalia markets which are important to save foreign currency and farmers are using newly released variety with low cost as compared to an imported seed. In Ethiopia, carrot production has been expanding mainly due to increasing urbanization and the recognition of carrots as an income and nutrition source (Getachew and Mohammed, 2012).

Additionally, the current investment policy in the country are favorable for expansion and diversification of vegetable crops both in the production and marketing sectors for export and foreign exchange earnings (Fekadu and Dandena, 2006). In order to encourage private investment, the Ethiopian Government has developed a package of incentives under Regulations No.84/2003 for investors engaged in new enterprises and expansions across a range of sectors (EIA, 2012). Horticultural crop production also creates jobs, on average it provides twice the amount of employment per hectare of production compared to cereal crop production (Cock, 2004).

Despite of its numerous importance and great countries production potential the production and productivities of carrot in Ethiopia is very low. This low productivity is attributed to many factors. The major ones are lack of improved seed, poor quality seeds that are expired and those with low germination percentage and no true to type variety are sold in the market and improper irrigation facilities (Betelhem, 2021). The type and the way producers are applying fertilizer are also the other serious problems in carrot production (Hailu *et al.*, 2008). Low productivity is also associated with other factors including lack of improved production practices, unavailability of technological inputs, pests and postharvest losses (Muendo *et al.,* 2004). Ethiopian soils lack most of the macro and micronutrients that are required to sustain optimal growth and development of crops (Hailu, 2014). This also becomes a major constraint to the production and productivity of carrots. Heavy losses are caused mainly due to price fluctuations, lack of guaranteed prices and unplanned planting patterns, lack of storage facilities, factors cause heavy post-harvest losses of most vegetables including carrots which are sold mainly in unprocessed form (Fekadu and Dandena, 2006).

2.4. Nutrient Requirements of Carrot

Soil is the basic pool of plant nutrients. However it does not contain adequate reserve to supply sufficient amounts of nutrient elements to meet the increasing requirements for higher production. Due to this reason, the application of optimum rate of fertilizer is needed for achieving higher production. Indeed, fertilization has significant importance in production costs and directly influences the carrot root production and quality (Joseph *et al.,* 2009b). High doses of fertilizers are often applied aiming to increase its root size, yield and improve its appearance to reach a good market price (Bruno *et al.,* 2007).The yield and quality of carrot are greatly affected by the fertilizers used (Win, 2010).

According to Rani and Mallareddy (2006), carrot is a heavy feeder of nutrients, and very sensitive to nutrient and soil moisture. Major mineral nutrients like N, P, and K play an important role in vegetative and reproductive phases of crop growth. Even though inorganic fertilization plays a vital role for healthy plant growth and development, it does affect soil health (Dauda *et al.,* 2008). In most cases, carrot farmers use inorganic fertilizers as the main source of nutrients supply to obtain higher growth and yield (Stewart *et al.,* 2005; Dauda *et al.,* 2008). The stimulating effect of increasing fertilizer levels on carrot growth was consistent with the growth enhancing effect of fertilizer on crop growth in general (Ryan, 2002).

The balance between the amount of nutrients that the soil can supply and the plant requirement to reach a certain yield should be considered for fertilizing as a rational method to optimize fertilizations. This method has consistent theoretical basis, which allows recommendations to be broader, without regionalist restrictions, and able to continuous improvement (Oliveira *et al.,* 2005; Santos *et al.,* 2008). Overall the balanced use of macro and micro nutrients had the highest effect on growth, yield and quality of carrot.

2.4.1. Effect of Nitrogen on Growth, Yield and Quality of Carrot

Nitrogen is considered an essential element for plants (Don Eckert, 2010). It is a major part of all amino acids and many other molecules essential for plant growth and other critical nitrogenous plant components viz., the nucleic acids and chlorophyll. It is also essential for carbohydrate use within plants. The availability of nitrogen in the soil positively and significantly affects the plant growth and development (Fageria and Baligar, 2005). In addition, it is essentially needed for increased root growth, crop canopy expansion and solar radiation interception in carrot (Sisay *et al.,* 2008; Don Eckert, 2010; Fageria and Moreira, 2013; Moniruzzaman *et al.,* 2013). Nitrogen supply also plays an essential role in the balance between vegetative and reproductive growth for plant including carrot (White *et al.,* 2007). It is very important nutrient in carrot production as the value of the other inputs cannot be fully realized unless it is applied to the crop in an optimum amount (Baniuniene and Zekaite, 2008).

Carrot demand for additional nitrogen fertilizer varies between 0-110 kg ha^{-1} (Salo, 2000). Great variation in nitrogen uptake may be related to different climatic conditions, soil type, nutrient concentration and well-developed root system which enable the plants to absorb nitrogen efficiently from the soil. About 85 - 90% of nitrogen is absorbed by carrot during the growth stage of plant; while in the first and last quarter of its growth only 10 -15% of nitrogen is absorbed (Mohammed, 2019). Its fertilization has been resulted in increased the average fresh weight, plant height, leaf number, root length, root diameter and dry weight (El-Desuki *et al.,* 2005; Ali *et al.,* 2006; Kandil, 2011; Moniruzzaman *et al.,* 2013). However, inappropriate application of nitrogen showed adverse effects on root development of plants.

Applications of nitrogen fertilizer can increase the yield and yield components of carrot (Moniruzzaman *et al.,* 2013). The highest total and marketable yield of carrot were obtained from the application of 150 kg N ha^{-1}(Ali *et al.,* 2006; Mehedi *et al.,* 2012).

Gutezeit and Gemuse (2000); Shanmugasundaram and Savithri (2002); and Chen *et al.* (2003) also described that yield of carrot was improved with application the of nitrogen fertilizers.

Quality of carrot is also enhanced with the application of nitrogen (Hochmuth, 2006; Moniruzzaman *et al.,* 2013). Its Deficiency caused higher ascorbic acid accumulation and lowers the carotenoid concentration (Kaack *et al.,* 2001). Its utilization and TSS content of roots increased with nitrogen rate up to 120 kg ha^{-1} (Chen *et al.,* 2003). Different nitrogen fertilizer levels also affected the TSS content in carrot slightly but significantly positive (El-Desuki *et al.,* 2005).

2.4.2. Effect of Phosphorus on Growth, Yield and Quality of Carrot

Among nutrients, phosphorus (P) is the fourth nutrient most taken up by carrot (Cecılio and Peixoto, 2013). In addition to participating in essential metabolic processes, such as photosynthesis and respiration, P is the cofactor of many enzymes and the structural component of phosphoproteins, phospholipids, and nucleic acids (Silva *et al.,* 2010). Deficiency of this nutrient negatively affects yield because it also reduces uptake of other nutrients (Flores *et al.,* 2012). However, in excess, it can reduce the availability of metallic micronutrients, such as zinc (Carneiro *et al.,* 2008; Muner *et al.,* 2011; Drissi *et al.,* 2015; Ova *et al.,* 2015). It is one of the most used in the carrot fertilization program, due to its importance in plant metabolism, being essential in plant establishment and development, because it favors the root system, increasing the absorption of water and nutrients, resulting in significant increments in root yield (Cíntia *et al.,* 2009; Mariana *et al.,* 2017).

In many soils plant-available Phosphorus is deficient and has to be supplemented with fertilizer and organic amendments (Mikhailova *et al.,* 2003; Osono and Takeda, 2005). Phosphorus is a nutrient that should therefore be available in adequate quantities from the early growth stages to maintain a high photosynthetic rate during root development (Hu *et al.,* 2010). Carrot growth and yield components like plant height, number of leaves, root length and root diameter, fresh weight of root, dry weight root and root yield, are greatly affected by phosphorus fertilization (McPharlin *et al.,* 2012; Nahar *et al.,* 2014). It is a heavy feeder of nutrients, which removes about 50 kg P_2O_5 per hectare. The crop is very sensitive to nutrient and soil moisture (Rani and MallaReddy, 2007). According to Nahar *et al.* (2014) the highest plant height, leaf number, root length, root diameter, shoot and root fresh weight, dry matter content of leaf and root, marketable and total root yield of carrot was recorded at the rate of 70 P_2O_5 kg ha^{-1}.

Additionally, the highest yield of turnip (24.9 t ha^{-1}) was recorded from the plants that received 100 kg P_2O_5 ha^{-1} while the lowest yield (19.1 t ha^{-1}) was recorded from the control treatment (Sadia *et al.,* 2013). Application of organic and inorganic fertilizers influenced the quality of carrot both at harvest. Ascorbic acid, reducing sugar, total sugar and titratable acidity of carrot were significantly affected by the different pre-harvest P fertilizer application (Sisay *et al.,* 2008).

2.4.3. Effect of Sulfur on Growth, Yield and quality of Carrot

Sulfur is essential for plant growth and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis and is required in similar amount (Ali *et al.,* 2008). Sulfur containing fertilizers also has positive effect on growth, yield, and yield parameters as well as quality of some vegetables (Chettri *et al.,* 2002; Choudhary, 2013). The increase in growth and yield of plants with application of sulfur can be explained with the increased metabolic activities, photosynthesis and assimilation (Sharma, 2015). Insufficient sulfur supply can affect yield and quality of crops, as sulfur required for protein and enzyme synthesis (Zhao *et al.,* 1999). Sulfur deficiency can affect nitrogen utilization by plants, leading to inefficient nitrogen uptake and utilization, further influencing overall plant health (Tandon *et al.,* 2007). The application of sulfur fertilizer rate and timing depend on factors like soil type and crop type. Proper sulfur fertilization practices help maximize crop productivity and promote sustainable agriculture (Meng *et al.,* 2004).

The increased plant height, leaf number, leaf length, fresh and dry weight of carrot was obtained from the application of 10 kg ha^{-1} of sulphur (Shoaib, 2021). Several studies revealed that the importance of sulphur achieve high carrot yield (Anjaiah and Padmaja, 2006). The application of sulphur up to 30 and 45 kg ha^{-1} significantly increased the edible root yields and dry matter production of carrot and radish, respectively (Singh *et al.,* 2016). Root length, root diameter, root dry weight and root yield of carrot was increased with increasing of sulphur rate (Shoaib, 2021). Application of sulphur also significantly affect dry matter content, total soluble solid, sugar and protein content of carrot root (Wafaa, 2013).

2.4.4. Effect of Blended NPS Fertilizer on Growth, Yield and Quality of Carrot

Fertilization has significant importance in production costs and directly influences the carrot root production and quality (Joseph *et al.,* 2009b). Most carrot farmers rely on synthetic fertilizers as their primary source of nutrients resulted in increased yield and quality (Stewart *et al.,* 2005; Dauda *et al.,* 2008). Optimum application of those fertilizers has significant role in crop production. An adequate supply of nutrients like N, P and S particularly in crop root zone might have improved the chemical and biological properties of soil and enabled plant roots to proliferate and resulting in better utilization of nutrients by crop (Bhandari *et al*., 2012). The application of NPS fertilizer significantly influenced the growth, yield and yield components of carrot crop (Mohammed, 2019; Isreal and Tamirat, 2023).

The increased rate of blended NPS fertilizer application leads to the increased plant height, leaf number, fresh weight of leaf, root length and diameter of carrot (Mohammed, 2019). According to (Isreal and Tamirat, 2023), the highest plant height and leaf number of carrot was observed by the application of 150 kg $ha^{-1}$of NPS. An increased level of NPS till 200 kg ha^{-1} increased the growth attributes of potato like plant height, leaf number per hill, leaf area, leaf area index, and stem number per hill and above ground dry biomass of potato (Gedefa *et al.,* 2022). Likewise 150 kg $ha^{-1}$of NPS increases plant height, leaf length Leaf number, and leaf width of garlic (Mulugeta *et al.,* 2024). NPS fertilizer had a significant effect on yield and yield contributing characters of carrot crop. The application of NPS fertilizer at the rate of 75: 100: 125: 150 kg ha^{-1} resulted in the highest root weight of carrot (Isreal and Tamirat, 2023). Similarly, Mohammed (2019) stated that the application of 200 kg $ha^{-1}$of NPS resulted in the highest root fresh and dry weight of carrot. The maximum total root yield and highest marketable root yield of carrot was observed from the application of NPS fertilizer at a rate of 150 kg ha^{-1}, which was significantly superior over the control (Isreal and Tamirat, 2023).

Applications of NPS fertilizer also significantly influence various quality parameters of carrot. As NPS fertilizer levels increased from 0 kg ha^{-1} to 200 kg ha^{-1}, TSS, root texture, root shape and titratable acidity of carrot increased significantly (Mohammed, 2019).

2.4.5. Effect of Boron on Growth, Yield and Quality of Carrot

Micronutrients are essentially as important as macronutrients to have better growth, yield and quality in plants (Yadav *et al.,* 2018). Boron (B) is one of the essential micronutrient which demands in cell walls formation, cell elongation, enzyme activation, sugars transport, carbohydrate metabolism, nucleic acid synthesis, root elongation, photosynthetic activities, RNA formation and metabolism (Marschner, 1995; Uchida, 2000; Broadley, *et al.,* 2012; Islam *et al.,* 2018). The primary role of boron in plants is to improve solubility and metabolism of Ca and its mobility and also helps in the absorption of nitrogen (Pandav *et al.,* 2016). Furthermore, it also promotes plant pigments and nutrient uptake and translocation (Day and Aasim, 2020). Boron deficiency in crops is more widespread than the deficiency of any other micronutrient (Gupta, 1993). It causes reduced plant height, growth, development, fruiting, and quality (Tohidloo and Souri, 2009; Souri and Bakhtiarizade, 2019), plants fail to produce panicles at the panicle formation stage (Rehman *et al.,* 2014) and tips of emerging leaves are white and rolled (Brdar-Jokanovic, 2020).

Furlani *et al.* (2003) stated that boron concentration in edible parts increased with the increase in boron application. Davies *et al.* (2003) also reported that the increase in boron application, increase the yield, improves the quality and decrease carrot damage. In addition, boron foliar applications also increased the vegetative growth, biochemical constituents and yield productivity of different vegetable crops (Abou ELYazied and Mady, 2012; El-Dissoky and AbdelKadar, 2013; Salim *et al.,* 2019). Minerals, carotenes and vitamin C concentrations of carrot root are also improved by boron supply (Singh *et al.,* 2012). The foliar application with micronutrients especially boron not only has major effects on flower formation, carbohydrate and protein metabolism, increases pollen germination and pollen tube growth, and yield (Gerendas and Sattelmatcher, 1990), but also is for chloroplast formation and sink limitations (Tersahima and Evans, 1988). The increased growth, yield and quality attributes of carrots were resulted from foliar application of boron at a rate of 500ppm as compared with the control treatment (Salim *et al.,* 2022).

2.4.6. The Effect of Blended NPS and B fertilizers on growth, yield and quality of carrot

Plant growth and development are largely determined by nutrient availability; therefore to ensure better productivity of crop plants, it becomes essential to understand the dynamics of nutrients uptake, transport, assimilation, and their biological interactions (Wawrzyńska and Sirko, 2014). All vegetables respond constructively to the application of small quantities of micro as well as macro-nutrients (Mallick and Mathukrishnan, 1980; Naz *et al.,* 2012). Macro and micro nutrients are also plays vital for the growth of plants, acting as catalyst in promoting various organic reactions taking place within the plant. To maintain sustainability in its production and nutritive value, it is becoming essential to replenish the depleting reserve of the micro and macronutrients in the soil or apply it through foliar spray to meet the immediate need of the crop (Amandeep and Simranjot, 2021).Application of nutrients helped in synthesis of greater amount of food materials which was later translocated into developing root resulting in increased root length and root diameter as described by Shanu *et al*. (2019).

Application of micronutrients in limited quantities and macronutrients, e.g., N, P or K, without phytotoxicity is the most effective usage of foliar nutritional methods (Oosterhuis and Weir, 2010). Foliar spray with micronutrients is one way to improve production and reduce environmental risks among other methods of application of plant nutrients. Moreover, it is easy and needs little infrastructure (Pandav *et al.,* 2016). Sultana *et al.* (2015) the combined application of NPK with B resulted in higher yield (14 and 18% respectively), higher uptake (47.8 and 93.1 g ha^{-1} respectively) and caused reduction in carrot damage (42 and 39% respectively). In addition, adding boron increased the P, K, Mg, carotenes and vitamin C concentrations in the storage roots of carrots (Singh *et al*., 2012).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted in Debre Berhan University, at the demonstration and research site of College of Agriculture and Natural Resource Sciences during the main growing season of 2022/23. The study area is located at 130 Km from the capital city of Addis Ababa with latitude and longitude of 9^{o} 39’24’’N and 39^{o} 31’17’’ E, respectively with an altitude of 2840 m a.s.l. Based on Ethiopian National Meteorological Agency data the study area is characterized by a bimodal rainfall pattern receiving a mean annual rainfall of 927.10 mm with a maximum (293.02 mm) and minimum (4.72 mm) peaks in August and December, respectively. The average monthly maximum and minimum temperatures range from 18.3 ^{O}C to 21.8 ^{O}C and from 2.4 to 8.9 ^{O}C, respectively. The most dominant soil type in the area is vertisol. Major crops which are cultivated in the study area are wheat, barely, pea, haricot bean, potato, carrot and garlic with mixed crop livestock, the farming practices in the area are conquered by sole cropping.

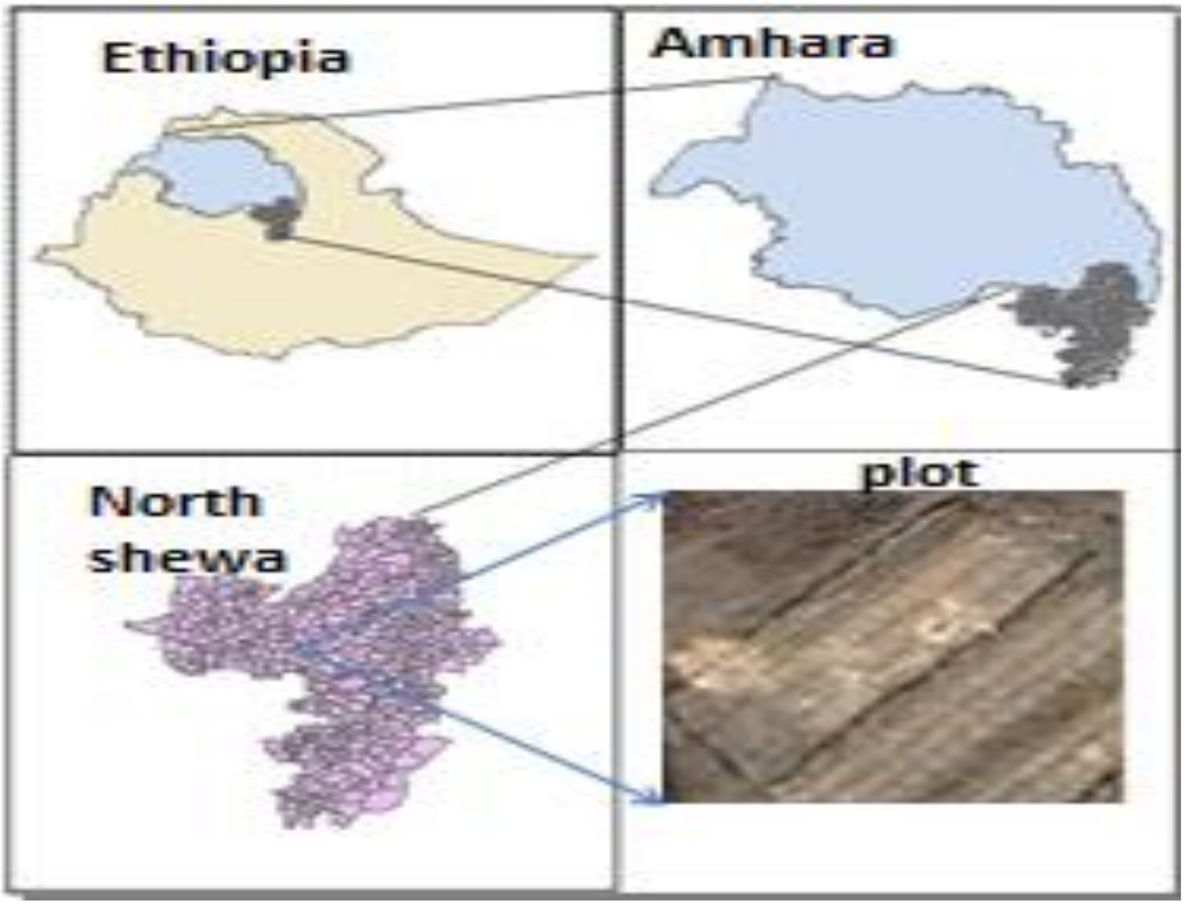

Figure 1. Map of the study area

3.2. Experimental Materials

Carrot variety "Nantes" was used as a test crop. The fertilizer sources were blended form of NPS (19% N, 38% P_2 O5 and 7% S), Urea [CO (NH2)2] (46% N) and, boric acid (H_3BO_3) (16% B) were used as experimental material.

Table 1. Agronomic and morphological characteristics of Nantes carrot variety

Cultivar	Origin	Maturity time (days)	Rainfall (mm)	Altitude (m.a.s.l)	Temperature (^{O}C)	Root color	Maintainer	Root length (cm)
Nantes	France	90-120	760-1010	1600-2400	15-20	Orange	Vilmorin-Andrieux Seed Company	12-15
Root yield (t ha^{-1})	Research field			47.26				
	Farmers' field			36.99 - 45.52				

Source: (Asfaw and Eshetu, 2015) and (Rose, 2021)

3.3. Treatments and Experimental Design

The treatments were consisted of 4x4 factorial combination of NPS fertilizer rates (0, 75, 150 and 225 kg ha^{-1}) and B rates (0, 250, 500 and 750ppm). The treatments were arranged in a randomized complete block design (RCBD) with three replications. Boron fertilizer was used at a rate of 500ppm based on Salim *et al.* (2022) as a form of boric acid (H_3BO_3).

3.4. Experimental Procedures

Before planting the experimental field was prepared following the conventional tillage practice to loosen the soil since carrots prefer deep and well-drained soils, deep ploughing at least 20-30 cm deep followed by harrowing, levelling, and cleaning. Soil was formed into a raised bed to obtain optimum drainage, maximum root length, and smoothness, to reduce soil compaction. Ridges and furrows were prepared using hand tools manually. The total area for the experimental field was=23.5m*6.5m (152.75m^2).Gross area=1m*1.5m (1.5m^2), while net plot size =0.8m*1m (0.8m^2).Each plot accommodates 6 rows and 20 plants in a row and contains 120 plants. The distance between blocks and plots were 1 m and 0.5 m respectively. The outer single rows at both sides of the plot and two plants at both ends of the rows were considered as border plants. The central 4 rows were used as the net plot area for all data collection.

Seeds of the “Nantes” carrot variety were used for propagation purposes. Seeds were directly sown at a spacing of 25cm x 5 cm between rows and plants, respectively on mid of May 2023 on a fine seed bed and immediately after sowing, all seedbeds were mulched uniformly to regulate the existing low temperature during germination period. The method of sowing was dropping the seeds after mixing with sand at a 1:1 ratio. After emergence the crop was thinned out. All the blended NPS fertilizers and half of urea at 100 kg ha^{-1} were applied on all treatments at the time of planting, however boron as boric acid was applied by foliar spray three times at 30, 55 and 75 days after sowing (Salim *et al.,* 2022) and the remain half of urea were applied after two months of sowing in band placement mode.
Weeding, irrigation, earthing up, and others production practices were done uniformly in all plots as per the recommended practices of the crop (Asfaw and Eshetu, 2015). Root yield was taken from the four central rows leaving boarder plants at each of end rows in both sides.

3.5. Soil Sampling and Analysis

Soil sample was taken randomly from the entire experimental field following a zigzag fashion from 0 to 30 cm depth before planting using augur. The soil sample was made in to a one kg composite sample. The composite soil sample was air-dried and crushed with pestle and mortar to pass through a 2 mm sieve size for the analysis of physical and chemical properties. Total nitrogen (TN %), available phosphorous (mg/kg), cation exchange capacity (cmol(+)/kg), exchangeable K ($Cmolkg^{-1}$), available S (mg/kg), available B (mg/kg), Organic Carbon(OC %), organic matter (OM %), soil pH (1:2.5), and soil texture was determined in the laboratory from the sample submitted. The pH of the Soil was estimated from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital EC and pH meter (Jones, 2003).

The textural class was determined by using the hydrometer method (Bouyoucos, 1962) and the Organic carbon of the soil was determined following the wet digestion method as described by Walkley and Black (1934) while the percentage of organic matter of the soil was determined by multiplying the percent organic carbon value by 1.724. The particle size distribution of the soils was analyzed by the Bouyoucos hydrometer method (Day, 1965). The exchangeable bases and CEC of the soil were determined by the ammonium acetate method (Van Reeuwijk, 1993). The total N content was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982) and available P, available S were determined by using Mehlich III multi-nutrient extraction procedure (Mehlich, 1984). Available B was determined using hot water method (Havlin *et al*., 1999), and K was determined by using dietylene triamine penta acetatic acid (AD-DTPA) method (Ryan *et al.*, 2001). A soil analysis was conducted at Debre Berhan Agricultural Research Center Soil Analysis Laboratories.

3.6. Data Collected

3.6.1. Phenological parameters

Days to 90% physiological maturity: It was recorded as the number of days required from sowing to the time when 90 % of the plants on a plot has their lower leaves turned to yellow.

3.6.2. Growth parameters

Plant height (cm): It was measured in cm from the ground level to the tip of mature leaf at the time of physiological maturity (when the lower leaves turns yellow and drop) one week before harvesting. Ten randomly selected plants from the central four rows per experimental plot was tagged and used for measurement of plant height.

Number of leaf per plant (No): Number of emerging leaf from the soil per plant of the ten randomly sampled plants from each treatment was counted at the time of physiological maturity.

Shoot Fresh weight (g/plant): The ten plants leaf was randomly selected from each plot at harvesting weighted using scale balance and expressed in grams.

Shoot dry weight (g/plant): The ten plants leaf was brought to the laboratory for oven drying. Then, samples were dried to a constant weight at 70^0C temperature and the dry weight was measured using digital sensitive balance.

3.6.3. Yield and yield-related parameters

Root length (cm): The distance from the leaf base or crown of the roots to the rounded root tip was measured using a ruler from ten randomly selected roots and expressed in cm.

Root diameter (cm): The root obtained from the central four rows was taken and the diameter was measured in the wider portion of the root using Verner caliper.

Average root weight (g/plant): The fresh weight of roots from the central four rows at harvest was recorded and the average fresh weight of roots was expressed in g/plant.

Root dry weight (g/plant): The root dry weight obtained from the central four rows was taken after chopping and oven drying. Samples were dried to a constant weight at 70^0C temperature and the root dry weight was measured using a digital sensitive balance.

Total root yield (t/ha): The yield of roots per hectare was computed from the entire net plot size and converted in to hectare bases and expressed in tons per hectare.

Marketable and unmarketable root number (No): The roots harvested from four central rows were grouped into marketable and unmarketable categories. Marketability of carrot roots was evaluated as described in (Carvalho *et al*., 2020) roots without external defects such as cracks, un-branched, forked, or green shoulder and with small modifications, a diameter ranging from1.5-2.5 cm and length 8-15cm was considered as marketable root. Based on these criteria, unmarketable roots included undersized, oversized, broken, rotten, misshapen, forked, hairy, dimpled, and others. Then after the marketable and unmarketable roots was counted separately for each treatment.

Marketable and unmarketable root yield (t/ha): the roots harvested from the central four rows were grouped into marketable and unmarketable categories. Marketability was evaluated in terms of texture and size of the root (Abiyot, 2008). Based on these criteria, unmarketable roots was included under size, oversized, broken, rotten misshapen, forked, hairy, dimpled and others. The judgment was done by local producers. It was multiplied with factor to get an estimated yield per hectare and expressed in tons per hectare. The weight of both marketable and unmarketable was taken and expressed in ton per ha.

Harvest index (%): It was calculated as the ratio of dry root yield weight to biological yield and multiplied by 100.

HI **(%)** = (EY/BY) *100

Where**:** EY: Weight of dry root (Economic Yield)

BY: Weight of biological yield (above-and below-ground dry weight).

3.6.4. Root quality parameters

Percent dry matter of root: One hundred g root was collected from ten randomly selected samples and cut into small pieces and then sun dried for two days. Sun dried samples were then put in paper packets and oven dried for 72 hours at 70 to 80°C in an oven. After oven drying, root was weighted. An electric balance was used to record the dry weight of root and it was calculated on percentage basis. The percentage of dry matter of roots was calculated by the following formula.

$$DM = \frac{[(DW + CW) - CW]}{[(FW + CW) - CW]} \times 100$$

Where: DM= dry matter, DW= dry weight, CW=container weight, FW= fresh weight

Total soluble solids: An aliquot of juice was extracted using a juice extractor (6001x model No.31JE35 6x.00777) from ten sample roots and 50 ml of the slurry was filtered using cheesecloth. The (TSS) was determined by a digital refracto-meter with a range of 0 to 32°Brix, and a resolution of 0.2 °Brix by placing 2 drops of clear juice on the prism. Between samples, the prism of the refracto-meter was washed with distilled water and dried before use. The refracto-meter was standardized against distilled water 0% TSS at Debre Berhan university horticulture laboratory.

pH: The extract of an aliquot of juice was prepared according to Nunes and Emond (1999). An aliquot of juice was first filtered with cheesecloth and the pH value of carrot juice was measured with a Metrohn 691 pH meter.

Root volume: Root volume was measured by taking random samples from each treatment and immersing them in a beaker containing a known amount of water. The volume of the root was determined by observing the displacement of the water by the root, so that the difference was taken as the volume of the root.

3.6.5. Partial Budget Analysis

The economic analysis was carried out by using the methodology described in CIMMYT (1988) approach which utilizes partial budgeting combined with marginal analysis. It reveals the economic performance of the treatments based on root yield of carrot. Gross return (yield x price) and net return (gross return - total varying cost) was calculated to carry out marginal rate of return (MRR) analysis which was important for correct evaluation of alternative technologies. The yield harvested from the plots was converted into hectare basis and the market value was calculated based on the existing market price.

Marginal rate of return (MRR %): it was calculated by dividing change in net benefit by change in cost.

$$\text{MRR \%} = \text{change in net benefit/ change in cost} * 100$$

A treatment having a marginal rate of return (MRR) greater than or equal to 100% is said to be economically profitable.

3.7. Data Analysis

Data were subjected to Analysis of Variance (ANOVA) using the general linear model (GLM) of the SAS statistical package version 9.31 (SAS, Institute Inc., 2012). All significant pairs of treatment means was compared using Duncan’s Multiple Range Test

(DMRT) (Gomez and Gomez, 1984) at a 5% level of significance. Correlation analysis was conducted for growth, yield and quality of carrot.

4. RESULTS AND DISCUSSION

4.1. Soil Physico-chemical Properties of the Experimental Site before Planting

Soil analysis indicated that the textural class of the surface soil in the study site was dominantly clay (Table 2). The EC and pH were non-saline (USSLS, 1954) and moderately acidic (Murphy, 1968), respectively. The crop grows better under non-saline (De Pascale and Barbieri, 2000; Alemu and Muluneh, 2019) and moderately acidic to alkaline soils (Getachew and Mohammed, 2013; Alemu and Muluneh, 2019), but preferentially a pH of 5.8-6.6 is better for the carrot production (Tindall, 1983; Rice *et al*., 1987). Since Landon (1991) and Hazelton and Murphy (2007) rated the CEC (cmol (+) kg^{-1}) of the soil less than 5 is very low, 5-15 is low, 15-25 is medium, 25-40 is high and greater than 40 is very high, the CEC of the soil was 29.79 cmol (+) kg^{-1} which was high (Table 2). Thus high CEC values imply that the soil has high buffering capacity against induced chemical changes. The organic carbon of the soil was 1.79% which was medium. Because, Tekalign (1991) described that the OC (%) of the soil less than 0.5 is very low, 0.5-1.5 is low, 1.5-3 is medium and greater than 3 is high. Whereas the organic matter of the soil was 3.09% which was medium as per the category of Tekalign (1991) that the OM (%) of the soil less than 0.86 is very low,0.86-2.59 is low, 2.59-5.17 is medium and greater than 5.17 is rated as high.

Since Tekalign (1991) further described the nitrogen content of soil between 0.12-0.25 percent is medium and greater than 0.25 % is high. The (TN %) content of the soil 0.21% (Table 2) was medium. Available P (mg kg^{-1}) content of the soil was 8.89 mg kg^{-1}. According to Olsen *et al*. (1954), the available P of the soil less than 5 is very low, 5-9 is low, 10-17 is medium, 18-25 is high, and greater than 25 is very high. The exchangeable K content of the soil was 1.58 (Cmol (+) kg^{-1}). According to FAO (2006), cation exchangeable soil potassium contents of greater than 1.2 (Cmol (+) kg^{-1}) soil is very high. The soil available sulfur of the experimental area was 18.09 mg kg^{-1}. Bashour and Sayegh (2007) reported that soils with Sulfur content of <0-10 is very low, 10-20 is low, 20-35 is medium, 35-45 is high and > 45 is very high. Thus, it has been rated as low. Available B (pmm) content of the soil was 0.9 ppm. According to Horneck *et al.* (2011) the available B (ppm) of the soil less than 0.2 very low, 0.2 - 0.5 low, 0.5-1.0 medium, 1.0-2.0 high and >2.0 very high. Thus it can be categorized medium.

The exchangeable Ca (cmol (+) kg^{-1}) content of the soil was 17.22 (cmol (+) kg^{-1}). Hazelton and Murphy (2007) described that the Exchangeable Ca of the soil less than 2 is very low, 2 -

5 is low, 5 -10 is medium, 10 - 20 is high and greater than 20 is very high. Thus, it has been rated as high. Exchangeable Mg (cmol kg^{-1}) content of the soil was 7.21 cmol (+) kg^{-1}). Hazelton and Murphy (2007) described that the Exchangeable Mg of the soil less than 0.3 is very low, 0.3 – 1.0 is low, 1.0 – 3.0 is medium, 3.0 – 8.0 is high and greater than 8.0 is very high. Thus, it has been rated as high. Exchangeable Na (cmol (+) kg^{-1}) content of the soil was 0.56 (cmol (+) kg^{-1}) which was medium. FAO (2006) described that the Exchangeable Na of the soil less than 0.10 is very low, 0.1 - 0.3 is low, 0.3 - 0.7 is medium, 0.7 - 2.0 is high and greater than 2.0 is very high.

Table 2. Physico-chemical characteristics of the soil in the experimental site.

Parameter	**Value**	**Rating**	**Reference**
Sand (%)	21		
Silt (%)	28		
Clay (%)	51		
Textural class	Clay		
pH	5.96	Moderately acidic	Murphy (1968)
Organic carbon (%)	1.79	Medium	Tekalign (1991)
Organic matter (%)	3.09	Medium	Tekalign (1991)
Total nitrogen (%)	0.21	Medium	Tekalign (1991)
Available P (mg kg^{-1})	8.89	Low	Olsen *et al*. (1954)
Exchangeable K (Cmol(+) kg^{-1})	1.58	Very high	FAO (2006)
Available S (mg kg^{-1})	18.09	Low	Bashour and Sayegh (2007)
B (ppm)	0.9	Medium	Horneck *et al.*(2011)
EC (ds ml^{-1})	0.098	Non-saline	USSLS, (1954)
CEC (Cmol(+) kg^{-1}	29.79	High	Landon (1991); Hazelton and Murphy (2007)
Ca^{2+} Cmol(+) kg^{-1}	17.22	High	Hazelton and Murphy (2007)
Mg^{2+} Cmol(+) kg^{-1}	7.21	High	Hazelton and Murphy (2007)
Na^{+} Cmol(+) kg^{-1}	0.56	Medium	FAO (2006)

Where: - pH= Potential of Hydrogen, OC = Organic Carbon; OM= Organic matter; N = Nitrogen; P = Phosphorus; S= Sulphur; B= boron; CEC = Cation Exchange Capacity; Ca = Calcium; Mg = Magnesium and Na = Sodium.

4.2. Phenological Parameters

4.2.1. Days to maturity

Days to maturity were significantly ($P \leq 0.01$) influenced by the main effect of NPS. On the other hand, the main effect of B and their interaction effect did not significantly affect this parameter (Appendix Table 1). The shortest days to maturity (127.23) were recorded from the nil fertilizer application. However, the longest day to maturity (154.65) was recorded from the application of the highest (225 kg ha^{-1}) NPS fertilizer rate which was statistically similar to150 kg ha^{-1} (Table 3). Carrot plants which were the nil application of NPS fertilizers had shortened days to maturity by 16.61 and 27.42 days as compared to the application of 150 and 225 kg ha^{-1} of NPS fertilizer (Table 3).

Table 3. Effect of NPS fertilizer on days to maturity of carrot

NPS rate (kg ha^{-1})	**Days to maturity**
0	127.23^{c}
75	137.70^{bc}
150	143.84^{ab}
225	154.65^{a}
Significance level	**
CV (%)	9.72

Means in the table followed by the different letter(s) are significantly different to each other at** = significant at $P \leq 0.01$; CV- coefficient of variation.

The increase in days to maturity could possibly be ascribed to enhanced vegetative growth due to high rate of NPS hence extended physiological activities and continuing in photosynthesis this implies increasing production of assimilates that caused a delay in maturity. In agreement with this, Chala *et al.* (2022) reported that the day to physiological maturity in onion crop was delayed at higher level of NPS (200 kg ha^{-1}) fertilizer application than the control treatment. Similarly, Gedefa *et al.* (2022) indicated that the longest day to maturity of potato was recorded from the application of 200 kg ha^{-1}NPS whereas the shortest days were obtained from the control treatment. On the contrary, Mohammed (2019) who reported that NPS fertilizer did not significantly affect days to maturity of carrot.

4.3. Growth parameters

4.3.1. Plant height

The analysis of variance indicated that the plant height was significantly ($p \leq 0.001$) affected by the main effects of NPS and boron whereas their interaction did not significantly affect this parameter (Appendix Table 1). The longest plant height (46.73 cm) was recorded from the application of 225 kg ha^{-1} of NPS fertilizer. However, the shortest plant height (28.57 cm) was recorded from the control (0 kg ha^{-1} of NPS) treatment (Table 4). The increase in plant height due to the application of the highest NPS fertilizer was by 18.16 and 6.89 cm as compared to the application of 0 and 150 kg ha^{-1} of NPS fertilizer, respectively. The increase in plant height of carrot might be due to the synergistic effect of N, P and S on metabolic activity in the early growth phase that caused vigorous vegetative growth; this in turn resulted in an increment of plant height. This result was in agreement with the finding of Isreal and Tamirat (2023) who found that the tallest plant height in carrot was recorded from the plant that received a higher amount of 150 kg ha^{-1}NPS fertilizer. However, the shortest was recorded from the control treatment. Similarly, Lefamo *et al.* (2019) reported that the longest plant height of carrot was obtained from the application of 150 kg ha^{-1} of NPS fertilizer while the shortest value was recorded from the control treatment. Mohammed (2019) also stated that the highest plant height was obtained from the application of NPS fertilizer at a rate of 200 kg ha^{-1} application of carrot. On the other hand, the lowest plant height was recorded from the control treatment.

The tallest plant height (39.87cm) was observed from the application of boron at a rate of 500ppm, which was statistically similar with the application of 750ppm boron. However, the shortest plant height (33.01 cm) was recorded from the control treatment (Table 4). The increase in plant height due to the application of 500ppm boron fertilizer was by 6.86 cm as compared to the control treatment. This might be attributed to the role of boron in nutrient uptake, sugars transportation and carbohydrate metabolism that favors vigorous vegetative growth. In line with this, Salim *et al.* (2022) reported that the longest plant height of carrot was obtained from the application of H_3BO_3 at 500ppm while the shortest value was recorded from the control treatment. In addition, Rahman *et al.* (2023) indicated that the tallest plant of tomato was observed from foliar application of H_3BO_3 at 175 ppm whereas the lowest was recorded from the control treatment.

Table 4. Effect of NPS and B fertilizers on plant height and leaf number of carrot

NPS rate (kg ha^{-1})	Plant height (cm)	Leaf number
0	28.57^{d}	7.55^{c}
75	32.49^{c}	9.49^{b}
150	39.84^{b}	11.73^{a}
225	46.73^{a}	11.93^{a}
Significance level	***	***
B rate (ppm)		
0	33.01^{c}	8.04^{d}
250	36.62^{b}	9.62^{c}
500	39.87^{a}	12.26^{a}
750	38.01^{ab}	10.77^{b}
Significance level	***	***
CV (%)	8.66	13.35

Means in the table followed by the different letter(s) are significantly different to each other *** = significant at P ≤ 0.001, CV- coefficient of variation.

4.3.2. Leaf number per plant

The main effects of NPS and boron rates significantly (P ≤ 0.001) influenced leaf number. However, their interaction did not significantly affect leaf number (Appendix Table 1).The application of the highest NPS (225 kg ha^{-1}) fertilizer resulted in the highest leaf number (11.93) of carrot which was statistically similar with 150 kg ha^{-1} NPS fertilizer application while the control treatment resulted in the lowest (7.55) (Table 4). The increase in leaf number due to the application of the highest level of NPS fertilization was by 58.01 and 1.71 % as compared to the application of 0 and 150 kg ha^{-1} of NPS fertilizer, respectively. The increase in leaf number from the higher level of NPS fertilizer application might be due its role on vegetative growth and increased photosynthetic activity which resulted in an increase in number of leaf of carrot. In line with this, Isreal and Tamirat (2023) reported that the highest leaf number was recorded from carrot which was supplied with 150 kg NPS fertilizer. On the other hand, the lowest leaf number was recorded from nil application. Similarly, Mohammed (2019) reported that the highest number of leaf was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application of carrot whereas the lowest leaf number was recorded from the control treatment.

The application of boron fertilizer at the rate of 500ppm resulted in the highest leaf number (12.26). On the other hand, the lowest leaf number (8.04) was recorded from the control treatment (Table 4). The increase in leaf number due to the application of boron (500ppm) fertilizer was by 52.49% as compared to the control treatment. This increment in leaf number might be due to the functioning of boron in number of growth processes like development of meristematic tissue, protein synthesis which caused activation of photosynthetic process and assimilates production and translocation to the plant parts. Similarly, Salim *et al.* (2022) stated that the highest leaf number of carrot was recorded from the application of H_3BO_3 at 500ppm while the lowest leaf number was obtained from the control treatment.

4.3.3. Shoot fresh weight

Shoot fresh weight of carrot was significantly ($P \leq 0.001$) affected by the main effects of NPS and boron. However, their interaction did not significantly affect this parameter (Appendix Table 1). The highest shoot fresh weight (33.12g) was obtained from the application of 225 kg ha^{-1} of NPS. On the other hand, the lowest shoot fresh weight (25.1g) was obtained from the control treatment (Table 5). The increase in shoot fresh weight due to the application of the highest NPS fertilizer was by 31.95 and 7.08 % as compared to the application of 0 and 150 kg ha^{-1} of NPS fertilizer, respectively. Increment of shoot fresh weight of carrot due to the application of highest NPS might have attributed to the availability of more nutrients that possibly increased the rate of cell division and elongation producing more leaves and their development caused vigorous vegetative growth with active photosynthetic process and assimilates production. In agreement with this, Mohammed (2019) reported that the highest shoot fresh weight of carrot was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application whereas the lowest value was recorded from the control treatment.

The application of boron fertilizer at the rates of 500ppm resulted in the highest shoot fresh weight (35.22g) while the lowest shoot fresh weight (22.86 g) was recorded from the control treatment (Table 5). The increase in shoot fresh weight due to the application of boron (500ppm) fertilizer was by 54.07 % as compared to the control treatment. This increment of shoot fresh weight in carrot due to the application of B fertilizer might be attributed to its role on activation of photosynthetic activity and assimilates production that led to vigorous vegetative growth. This in turn resulted in production of more leaf per plant and increased the fresh weight of shoot. In agreement with this, Salim *et al.* (2022) indicated that the increased shoot fresh weight of carrot was obtained from the application of H_3BO_3 at 500ppm as compared to the control treatment. In addition, Shaimaa and Soad (2014) stated that the highest shoot fresh weight of tomato was obtained from B at 100ppm whereas the lowest was recorded from the control treatment.

Table 5. Effect of NPS and B fertilizer rates on shoot fresh and dry weight of carrot

NPS rate ($kgha^{-1}$)	Shoot fresh weight(g)	Shoot dry weight(g)
0	25.1^{d}	9.21^{d}
75	28.62^{c}	11.28^{c}
150	30.93^{b}	13.49^{b}
225	33.12^{a}	14.59^{a}
Significance level	***	***
B rate (ppm)		
0	22.86^{d}	8.24^{d}
250	28.47^{c}	12.05^{c}
500	35.22^{a}	14.87^{a}
750	31.22^{b}	13.41^{b}
Significance level	***	***
CV(%)	4.5	6.17

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$, CV- coefficient of variation.

4.3.4. Shoot dry weight

The analysis of variance indicated that the shoot dry weight was significantly ($p \leq 0.001$) influenced by the main effects of NPS and boron while their interaction did not significantly affect this parameter (Appendix Table 1). The highest shoot dry weight (14.59g) was obtained from the application of 225 kg ha^{-1} of NPS. However, the lowest shoot dry weight (9.21g) was obtained from the control treatment (Table 5). The increase in shoot dry weight due to the application of highest NPS was by 58.41 and 8.15 % as compared to the application of 0 and 150 kg ha^{-1} of NPS fertilizer, respectively. The increase in shoot dry weight of carrot in response to the increased levels of NPS might be attributed to maximum vegetative growth, increased photosynthetic product and accumulation of carbohydrates; this in turn resulted in an increased shoot dry weight of carrot. In agreement with this, Mohamed and Wagi (2021) also described that the highest dry weight of shoot of onion was obtained from the application of 250 kg NPS ha^{-1} fertilizer whereas the lowest value was observed from the control treatment.

The application of boron fertilizer at the rates of 500ppm resulted in the highest shoot dry weight (14.87g). On the other hand, the lowest shoot dry weight (8.24g) was recorded from the control treatment (Table 5). The increase in shoot dry weight due to the application of boron (500ppm) fertilizer was by 80.46 % as compared to the control treatment. The increase in shoot dry weight in response to the application of B might be attributed to the fact that its role in metabolic process with enhanced photosynthetic activity and photosynthates production and partitioning to the plant parts, this leading to highest dry matter accumulation in to the shoot. In agreement with this Shaimaa and Soad (2014) stated that the highest shoot dry weight of tomato was obtained from B at 200ppm while the lowest was recorded from the control treatment.

4.4. Yield and Yield Components

4.4.1. Average root weight

The main effects of NPS and boron significantly ($P \leq 0.001$) affected average root weight of carrot whereas their interaction did not significantly affect this parameter (Appendix Table 2). The highest average root weight (102.52g) was obtained from the application of 225 kg ha^{-1} of NPS. However, the lowest value (62.39g) was obtained from the control treatment (Table 6). The increase in average root weight due to the heights application of NPS fertilizer was by 64.32 and 19.2 % as compared to the application of 0 and 150 kg ha^{-1} of NPS fertilizer, respectively. Increasing in average root weight of carrot could be ascribed to the increased and readily availability of nutrients which caused vigorous vegetative growth and assimilate production with translocation of photosynthetic product to the root, this in turn results an increased in average root weight.

Table 6. Effect of NPS and B fertilizer rates on average root weight of carrot

NPS rate (kgha^{-1})	Average root weight(g)
0	62.39^{c}
75	66.76^{c}
150	86.01^{b}
225	102.52^{a}
Significance level	***
B rate (ppm)	
0	66.72^{d}
250	74.98^{c}
500	91.35^{a}
750	84.63^{b}
Significance level	***
CV(%)	10.23

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$, CV- coefficient of variation.

In agreement with this, Isreal and Tamirat (2023) indicated that the highest average root weight of carrot was recorded from the plant which received 150 kg NPS fertilizer. On the other hand, the lowest value was recorded from the control treatment. Similarly, Mohammed (2019) reported that the highest average root weight of carrot was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application while the lowest value was recorded from the control treatment.

The application of boron fertilizer at the rates of 500ppm resulted in the highest average root weight (91.35g). However, the lowest average root weight (66.72 g) was recorded from the control treatment. The increase in average root weight due to the application of boron (500ppm) fertilizer was by 36.92 % as compared to the control treatment. This might be attributed to the available B nutrient that caused translocation of photo assimilates and other soluble solids to the root and resulted in the highest average root weight of carrot. In line with this, Salim *et al.* (2022) reported that the highest average root weight of carrot was obtained from the application of H_3BO_3 at 500ppm whereas the lowest value was recorded from the control treatment.

4.4.2. Root dry weight

The root dry weight of carrot was significantly ($P \leq 0.001$) affected by the main effects of NPS and boron as well as by their interaction effect (Appendix Table 2). The highest root dry weight (19.34g) was attained from the combined application of 150 kg ha $^{-1}$ of NPS with 500ppm boron rate. On the other hand, the lowest root dry weight (8.99g) was obtained from the control treatment (Table 7).

Table 7. Interaction effects of NPS and Boron fertilizers on root dry weight of carrot.

NPS rate (kg ha^{-1})	B rate (ppm)	Root dry weight(g)
0	0	8.99^{i}
	250	10.53^{gh}
	500	12.35^{ef}
	750	11.12^{fg}
75	0	9.6^{hi}
	250	12.37^{ef}
	500	14.28^{d}
	750	12.53^{e}
150	0	11.54^{e-g}
	250	15.63^{c}
	500	19.34^{a}
	750	17.18^{b}
225	0	10.77^{gh}
	250	14.35^{d}
	500	17.29^{b}
	750	16.1^{bc}
Significance level		***
CV(%)		5.63

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$; CV- coefficient of variation.

The increase in root dry weight due to the application of 150 kg ha^{-1} of NPS and 500ppm boron fertilizer was by 115.13 and 67.59 % as compared to the control treatment and 150 kg ha^{-1} of NPS with 0ppm boron fertilizer. Such increment of root dry weight could be attributed to the readily availability of NPS and B this implies increased vegetative growth through activated photosynthetic activity and assimilates production and partitioning to the plant parts. This eventually causes an increased accumulation in root.

Similarly, Mohammed (2019) stated that the highest root dry weight of carrot was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application. However, the lowest root dry weight was recorded from the control treatment.

4.4.3. Root length

Root length was significantly ($P \leq 0.001$) influenced by the main effects NPS, boron, and their interaction ($P \leq 0.01$) (Appendix Table 2). The longest root length (14.98 cm) was measured from the combined application of 150 kg ha^{-1} NPS and 0500ppm of boron fertilizer application. However, the smallest root length (7.12 cm) was recorded from the control treatment (Table 8). The increase in root length due to 150 kg ha^{-1} of NPS with 500ppm of boron combination was by 110.39 and 34.11% as compared to the control treatment and 150 kg ha^{-1} of NPS with 0ppm of boron, respectively. This might be due to those abundantly available nutrients that enhanced vigorous vegetative growth and also helped in synthesis of greater amount of photosynthetic product, which was later translocated into developing root. This consequently resulted in an increased root length.

This result is in agreement with Mohammed (2019) who reported that the highest root length was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application of carrot whereas the lowest was recorded from the control treatment. Salim *et al.* (2022) indicated that the longest root length of carrot was obtained from the application of H_3BO_3 at 500ppm. On the other hand, the shortest root length was recorded from the control treatment.

4.4.4. Root diameter

The analysis of variance indicated that root diameter was significantly ($P \leq 0.001$) influenced by the main effects NPS, boron and there interaction ($P \leq 0.01$) (Appendix Table 2). The widest root diameter (2.45 cm) was measured from the combined applications of 150 kg ha^{-1} NPS fertilizer with 500ppm boron rate. On the other hand, the narrowest root diameter (1.52 cm) was recorded from the control treatment (Table 8).

Table 8. Interaction effects of NPS and Boron fertilizers on root length and diameter of carrot.

NPS rate ($kgha^{-1}$)	B rate (ppm)	Root length (cm)	Root diameter(cm)
0	0	7.12^{j}	1.52^{i}
	250	9.3^{i}	1.84^{gh}
	500	11.87^{e-g}	2.18^{c-e}
	750	10.78^{h}	2.09^{ef}
75	0	8.94^{i}	1.8^{h}
	250	11.39^{f-h}	2.03^{ef}
	500	12.9^{cd}	2.33^{a-c}
	750	11.78^{e-g}	2.19^{c-e}
150	0	11.17^{gh}	1.87^{gh}
	250	12.27^{d-f}	2.3^{b-d}
	500	14.98^{a}	2.45^{a}
	750	12.59^{c-e}	2.34^{a-c}
225	0	10.66^{h}	1.96^{fg}
	250	11.34^{f-h}	2.37^{ab}
	500	14.11^{b}	2.3^{a-d}
	750	13.22^{c}	2.14^{de}
Significance level		**	**
CV(%)		4.49	4.23

Means in the table followed by the different letter(s) are significantly different to each other at **= significant at $P \leq 0.01$; CV- coefficient of variation.

The application of NPS at a rate of 150 kg ha^{-1} with 500ppm boron increased root diameter by 61.18 and 31.02% as compared to the control treatment and 150 kg ha^{-1} of NPS with 0ppm boron, respectively. The increment in root diameter might be due to the positive effects of N, P&S as well as B in providing a sufficient nutrients to the plant, this caused increase in vegetative growth and accelerate photosynthesis process as well as production of assimilate that in turn led to the increased translocation of assimilates into the carrot roots and resulted in increased root diameter.

Similarly, Mohammed (2019) reported that the widest root diameter was obtained from the highest NPS fertilizer (200 kg ha^{-1}) application of carrot whereas the narrowest root diameter was recorded from the control treatment. Salim *et al.* (2022) stated that the widest root diameter of carrot was obtained from the application of H_3BO_3 at 500ppm while the lowest root diameter was recorded from the control treatment.

4.4.5. Marketable root yield

The main effects of NPS and boron significantly ($P \leq 0.001$) affected the marketable root yield of carrot and there interaction ($P \leq 0.05$) (Appendix Table 3). The highest marketable root yield (56.28 t ha^{-1}) was attained from the combined application of 150 kg ha^{-1} of NPS with a 500ppm boron rate. However, the lowest marketable root yield (28.99 t ha^{-1}) was obtained from the control treatment (Table 9). The increase in marketable root yield due to the application of 150 kg ha^{-1} of NPS and 500ppm boron fertilizer was by 94.03 and 37.30% as compared to the control treatment and 150 kg ha^{-1} of NPS with 0ppm boron fertilizer, respectively. The higher marketable yields obtained from the combined application of 150 kg ha^{-1} of NPS with 500ppm boron fertilizer might be due to the vigorous vegetative growth of carrot that encouraged by the balanced fertilizer application which led to higher carbohydrate metabolism and chlorophyll synthesis which resulted in increased photosynthetic activity of plant, production of assimilates and translocation of photosynthates towards root that imply the increase in yield which resulted in higher proportion of marketable root length, diameter and weight.

In line with this, Isreal and Tamirat (2023) indicated that the highest marketable root yield of carrot was recorded from the plant which received 150 kg NPS fertilizer whereas the lowest marketable root yield was recorded from the control treatment. In addition, Mekides *et al*. (2020) described that the highest and the lowest value of marketable root yield in potato were obtained by the application of NPS at 55.5: 89.7:16.52 kg ha^{-1} and the control treatment, respectively.

4.4.6. Unmarketable root yield

Unmarketable root yield of carrot was significantly ($P \leq 0.001$) affected by the main effects NPS, boron and their interaction ($P \leq 0.01$) (Appendix Table 3). The highest unmarketable root yield (10.00 t ha^{-1}) was attained from the control treatment. However, the lowest unmarketable root yield (2.4 t ha^{-1}) was obtained from the combined application of 150 kg ha^{-1} of NPS with 500ppm boron rate (Table 9).

Table 9. Interaction effects of NPS and Boron fertilizers on marketable and unmarketable root yield of carrot.

NPS rate (kg ha^{-1})	B rate (ppm)	Marketable root yield (t ha^{-1})	Unmarketable root yield(t ha^{-1})
0	0	28.99^{j}	10.00^{a}
	250	34.59^{hi}	8.67^{ab}
	500	35.09^{hi}	6.33^{cd}
	750	32.33^{ij}	7.67^{bc}
75	0	36.59^{g-i}	6.52^{cd}
	250	37.34^{f-i}	6.0^{de}
	500	39.91^{f-h}	6.27^{cd}
	750	36.67^{g-i}	6.34^{cd}
150	0	40.99^{e-g}	5.86^{de}
	250	52.64^{ab}	3.67^{hi}
	500	56.28^{a}	2.4^{i}
	750	47.63^{b-d}	4.28^{f-h}
225	0	41.96^{e-g}	5.67^{d-f}
	250	49.08^{bc}	4.0^{gh}
	500	46.31^{c-e}	4.67^{e-h}
	750	42.87^{d-f}	5.33^{d-g}
Significance level		*	**
CV(%)		7.29	13.77

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; **= significant at $P \leq 0.01$; CV- coefficient of variation.

The increment of unmarketable root yield from the control treatment might be due to the insufficient supply of NPS and boron fertilizers that resulted in lower vegetative growth which possibly had developed under sized root that might led to the development of small root weight that in turn resulted in higher proportion of unmarketable root yield.

In agreement with this study, Gedefa *et al.* (2022) reported that the maximum unmarketable tuber yield of potato was observed from the control treatment while the lowest was recorded from the application of 200 kg $ha^{-1}$of NPS. In addition, Nardos (2021) also stated that the maximum unmarketable yield of tomato was observed from the control treatment whereas the lowest was recorded from the application of 240 kg ha^{-1}NPS.

4.4.7. Total root yield

The analysis of variance indicated that the main effects of NPS and boron fertilizer significantly ($P \leq 0.001$) affected total root yield and their interaction ($P \leq 0.05$) (Appendix Table 3). The highest total root yield (58.68 t ha^{-1}) was attained from the combined application of 150 kg ha^{-1} of NPS with 500ppm boron. However, the lowest total root yield (38.99 t ha^{-1}) was obtained from the control treatment (Table 10). The increase in total root yield due to the application of 150 kg ha^{-1} of NPS and 500ppm boron fertilizer was by 50.5 and 25.22% as compared to the control treatment and 150 kg ha^{-1} of NPS and 0ppm boron, respectively. The increment in total root yield due to the better efficiency of NPS in combination with B could be attributed to better availability and uptake of nutrients that could have enhanced vigorous vegetative growth, activated plant metabolism and photosynthetic rate which resulted in the increased amount of assimilates that could be partitioned to the storage organs which consequently led to maximum root yield. Furthermore, this increased yield may be due to the cumulative effect of all yield components viz., root length, root diameter, fresh and dry weight of root. In agreement with this, Isreal and Tamirat (2023) also indicated that the highest root yield of carrot was recorded from the plant which received 150 kg NPS fertilizer whereas the lowest root yield was recorded from the control treatment. Similarly, Mekides *et al.* (2020) stated that the highest and the lowest value of total tuber yield in potato were obtained by the application of N: P_2O_5: S at 55.5: 89.7:16.52 kg ha^{-1} and the control treatment, respectively.

Salim *et al.* (2022) stated that the highest carrot root yield was observed from the application of H_3BO_3 at 500ppm. However, the lowest root yield was obtained from the control treatment. In addition, Rahman *et al.* (2023) reported as the highest tomato yield was observed from foliar application of H_3BO_3 at 175ppm while the lowest was recorded from the control treatment.

4.4.8. Harvest index

Harvest index was significantly ($P \leq 0.001$) influenced by the main effects NPS, boron, and their interaction ($P \leq 0.01$) (Appendix Table 3). The highest harvest index (83.67%) was measured from the combined application of 150 kg ha^{-1} of NPS with 500ppm boron which was statistically similar to the application of 225 kg ha^{-1} of NPS with 250ppm boron. On the other hand, the lowest harvest index (70.44%) was obtained from the control treatment (Table 10). The increase in harvest index due to the application of 150 kg ha^{-1} of NPS with 500ppm boron was by 18.78 and 10.57% as compared to the control treatment and 150 kg ha^{-1} of NPS with 0ppm boron, respectively. The increment in harvest index due to the application of N, P, S & B might be attributed to the role of those readily available nutrients which caused to increases in vegetative growth and photosynthetic rate that implies the increased amount of assimilate that could be translocated to the root which consequently increased the harvest index. In line with this, Abera (2020) found that the maximum harvest index in garlic was due to the application of 50 kg ha^{-1} of nitrogen-blended NPS fertilizer and the lowest from the control treatment. However, Mekides *et al*. (2020) stated that the increased in the rate of NPS fertilizer led to lower harvest index of potato.

Table 10. Interaction effects of NPS and Boron fertilizers on total root yield and harvest index (%).

NPS rate (kg ha^{-1})	B rate (ppm)	Total root yield(t ha^{-1})	Harvest index (%)
0	0	38.99^{h}	70.44^{g}
	250	43.25^{gh}	72.33^{e-g}
	500	41.42^{h}	73.67^{d-g}
	750	40.00^{h}	72.00^{e-g}
75	0	43.26^{gh}	71.33^{fg}
	250	43.34^{gh}	74.33^{d-g}
	500	46.18^{fg}	77.00^{cd}
	750	43.00^{gh}	75.33^{c-f}
150	0	46.86^{e-g}	75.67^{c-f}
	250	56.31^{ab}	76.33^{c-e}
	500	58.68^{a}	83.67^{a}
	750	51.91^{b-d}	79.00^{bc}
225	0	47.63^{d-g}	76.33^{c-e}
	250	53.08^{bc}	82.67^{ab}
	500	50.98^{c-e}	77.33^{cd}
	750	48.21^{d-f}	74.33^{d-g}
Significance level		*	**
CV(%)		5.36	3.12

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; CV- coefficient of variation.

4.4.9. Marketable root numbers of carrot

The main effects NPS and boron significantly ($P \leq 0.001$) affected marketable root number and their interaction ($P \leq 0.05$) (Appendix Table 3). The highest marketable root number (43.33) was obtained from the combined application of 150 kg ha^{-1} of NPS with 500ppm boron. However, the lowest marketable root number (23.00) was obtained from the control treatment (Table 11). The increment of marketable root numbers due to NPS and B fertilizer application could be attributed to the readily availability of nutrients to the plant, which promoted vigorous vegetative growth through facilitated nutrients uptake and translocation and also caused root growth. This results increased marketable root numbers of carrot in terms of roots without external defects and with a good root length and diameter, which can pass for the grading on marketability. In agreement with this, Gedefa *et al.* (2022) who indicated that the highest marketable tuber number of potato was recorded from the application of 200 kg ha^{-1}NPS whereas the lowest marketable tuber number was obtained from the control treatment.

4.4.10. Unmarketable root numbers of carrot

The analysis of variance indicated that unmarketable root number was significantly (P ≤ 0.001) influenced by the main effects NPS, boron and there interaction (P ≤ 0.01) (Appendix Table 3). The highest unmarketable root number (27.00) was obtained from the control treatment. However, the lowest unmarketable root number (6.67) was obtained from the combined application of 150 kg ha $^{-1}$ of NPS with 500ppm boron. (Table 11).

Table 11. Interaction effects of NPS and Boron fertilizers on marketable and unmarketable root number of carrot.

NPS rate (kg ha^{-1})	B rate (ppm)	Marketable root (No)	Unmarketable root (No)
0	0	23.00^{g}	27.00^{a}
	250	28.33^{ef}	21.67^{b}
	500	31.67^{de}	18.33^{c}
	750	25.00^{fg}	25.00^{a}
75	0	33.33^{d}	16.67^{cd}
	250	36.00^{b-d}	14.00^{e}
	500	38.67^{a-c}	11.33^{f}
	750	35.33^{cd}	14.67^{de}
150	0	39.67^{a-c}	10.33^{fg}
	250	41.67^{a}	8.33^{gh}
	500	43.33^{a}	6.67^{h}
	750	40.67^{ab}	9.33^{fg}
225	0	40.00^{a-c}	10.00^{fg}
	250	41.00^{ab}	9.00^{f-h}
	500	40.33^{a-c}	9.67^{fg}
	750	40.27^{a-c}	9.72^{fg}
Significance level		*	**
CV(%)		7.33	10.11

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at P ≤ 0.05; **= significant at P ≤ 0.01; CV- coefficient of variation.

The increment of unmarketable root numbers of carrot from the control treatment might be attributed to the insufficient supply of NPS and B fertilizer that consequently resulted in decreased vegetative growth which may reduce sugars transportation and carbohydrate metabolism process which caused the development of undersized and deformed roots. In agreement with this, Gedefa *et al.* (2022) described that the highest unmarketable tuber number of potato was recorded from the control treatment. On the other hand, the lowest unmarketable tuber number was obtained from the application of 200 kg ha^{-1}NPS which was statistically similar with the application of 150 kg ha^{-1} of NPS. Similarly, Getacher (2021) stated that the highest unmarketable root number of potato was obtained from the control treatment whereas the lowest unmarketable root number was recorded from 180 kg ha^{-1} NPS.

4.5. Quality Attributes

4.5.1. Percent dry matter

Percent dry matter content was significantly ($P \leq 0.001$) affected by the main effects NPS and boron rate as well as by their interaction effect (Appendix Table 4). The highest percent dry matter content (45.7) was attained from the combined application of 150 kg ha $^{-1}$ of NPS with 500ppm boron rate. However, the lowest percent dry matter content (27.65) was obtained from the control treatment (Table 12).

Table 12. Interaction effects of NPS and Boron fertilizers on percent dry matter content of carrot.

NPS rate (kg ha^{-1})	B rate (ppm)	Percent dry matter content (%)
0	0	27.65^{i}
	250	29.65^{g-i}
	500	34.89^{de}
	750	32.18^{fg}
75	0	29.19^{hi}
	250	31.79^{g}
	500	37.27^{d}
	750	34.46^{ef}
150	0	30.58^{gh}
	250	40.38^{c}
	500	45.7^{a}
	750	41.3^{bc}
225	0	31.9^{g}
	250	37.13^{d}
	500	43.42^{ab}
	750	42.92^{b}
Significance level		***
CV(%)		3.96

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$; CV- coefficient of variation.

The increase in percent dry matter content due to the application of 150 kg ha^{-1} of NPS and 500ppm boron fertilizer was by 65.28 and 49.44% as compared to the control treatment and 150 kg ha^{-1} of NPS and 0ppm boron fertilizer, respectively. This might be ascribed to the proper amount of NPS and B caused higher available nutrients, considerably enhanced the vegetative growth of the plant and promotes dry matter accumulation through its action on activation of photosynthetic activity and translocation to the storage root. Similarly, Gedefa *et al.* (2022) described that the highest dry matter content of potato was recorded from the application of 200 kg ha^{-1}NPS. On the other hand, the lowest dry matter content was recorded from the control treatment.

4.5.2. Total soluble solid

The main effects NPS and boron significantly ($P \leq 0.001$) affected total soluble solids of carrot whereas their interaction did not significantly affect this parameter (Appendix Table 4). The highest total soluble solid (13.04°Brix) was measured from the application of 150 kg ha^{-1} of NPS. On the other hand, the lowest value for total soluble solid (7.23°Brix) was obtained from the control treatment (Table 13). The increase in total soluble solid was by 80.36% as compared to the control treatment. The increase in TSS might be due to the sufficient amount of NPS that increased vegetative growth and photosynthesis activity which produce a higher amount of photo assimilates and translocation to the root that caused increased TSS content of carrot roots.

In line with this, Mohammed (2019) stated that the highest TSS value of carrot was obtained from the highest NPS (200 kg ha^{-1}) fertilizer application which was statistically similar with 150 kg ha^{-1} of NPS levels and the lowest TSS value was recorded from the control treatment. In addition, Nardos (2021) reported that the highest and the lowest value of total soluble solid in tomato fruit were obtained by the application of 240 kg ha^{-1} of NPS and the control treatment, respectively.

The application of boron fertilizer at the rate of 500ppm resulted in the highest total soluble solid (12.27°Brix). However, the lowest total soluble solid (7.99°Brix) was recorded from the control treatment (Table 13). The increase in total soluble solids due to the application of Boron fertilizer was by 53.57 % as compared to the control treatment. The increase in TSS due to the contribution of B for quality attribute as total soluble solid might be ascribed to its role in increased carbohydrates metabolism during photosynthesis and contributed to the efficient translocation of photosynthates to the root. In agreement with this, Salim *et al.* (2022) indicated that the highest total soluble solids of carrot were obtained from the application of H_3BO_3 at 500ppm while the lowest value was observed from the control treatment.

Table 13. Effect of NPS and Boron fertilizers on TSS of carrot

NPS rate (kg ha^{-1})	**TSS(**◦Brix)
0	7.23^{d}
75	9.04^{c}
150	13.04^{a}
225	11.04^{b}
Significance level	***
B rate (ppm)	
0	7.99^{c}
250	9.42^{b}
500	12.27^{a}
750	10.68^{b}
Significance level	***
CV(%)	16.94

Means in the table followed by the different letter(s) are significantly different to each other *** = significant at $P \leq 0.001$, CV- coefficient of variation.

4.5.3. pH

The analysis of variance indicated that pH value was significantly ($P \leq 0.05$) influenced by the main effect NPS. However, the main effect Boron and their interaction effect did not significantly affect this parameter (Appendix Table 4). The highest pH (6.40) was measured from the control treatment which was statistically similar with 75 and 150 kg ha^{-1} of NPS levels while the lowest value (6.0) was obtained from the application of 225 kg ha^{-1} of NPS (Table 14). The pH of carrot root affected by NPS fertilizer might be attributed to the high nutrient composition present in NPS which makes a difference in the pH content. In line with this, Mohammed (2019) indicated that the highest pH value of carrot was obtained from the control treatment whereas the lowest pH value was recorded from the application of 200 kg ha^{-1} of NPS.

4.5.4. Root volume

The root volume was significantly ($P \leq 0.001$) affected by the main effect NPS. On the other hand, the main effect Boron as well as their interaction did not significantly affect this parameter (Appendix Table 4). The highest Root volume (92.42 cm^{3}) was measured from the application of 150 kg ha^{-1} of NPS whereas the lowest value (58.00 cm^{3}) was obtained from the control treatment (Table 14). The increases in root volume of carrot due to the balanced amount of N, P&S might be attributed to the abundantly available nutrients which helped in vigorous vegetative growth and increased in photosynthesis activity with better assimilation to the root, consequently there was increased in size and weight of root. Similarly, Demoz (2016) also stated that the highest root volume of head cabbage was obtained from the application of 102.5:115:21.18 NPS kg ha^{-1} while the lowest value was recorded from the control treatment.

Table 14 . Effect of NPS fertilizers on Root volume of carrot

NPS rate (kg ha^{-1})	**pH**	**Root volume(cm^3)**
0	6.40^{a}	58.00^{d}
75	6.35^{a}	68.00^{c}
150	6.11^{ab}	92.42^{a}
225	6.0^{b}	83.32^{b}
Significance level	*	***
CV(%)	5.74	8.46

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; at ***= significant at $P \leq 0.001$; CV- coefficient of variation.

4.6. Correlation Analysis for Growth, Yield and Some Quality Parameters of Carrot

Correlation analysis on growth, yield and quality of carrot revealed both positive and negative correlation (Table 15). Total root yield was significantly and positively correlated with days to maturity (r=0.36*), plant height (r=0.65***), leaf number (r=0.69***), shoot fresh weight (r=0.56***) and shoot dry weight (r=0.62***). This might be due to the increased vegetative growth of the plant resulted in the production of high photo assimilation that in turn resulted in increased root yield carrot. Betelhem (2021) also indicated that total root yield of carrot had a positive correlation with growth attributes (plant height, leaf number, shoot fresh and dry weight).

The correlation analysis further indicated that the total root yield of carrot was significantly and positively correlated with average root weight (r=0.59***), root dry weight (r=0.38**), root length (r=0.55***), root diameter (r=0.60***), marketable root yield (r=0.98***), marketable root number (r=0.75***), harvest index (r=0.81***), dry mater content (r=0.70***), total soluble solid (r=0.74***) and root volume (r=0.83***) (Table 14). Such significant and positive correlation of yield of carrot with most of the yield component and quality parameters was a result of increase in yield and yield component of carrot which caused to enhanced root in weight and number that in turn resulted in increased root yield and quality. Betelhem (2021) also indicated that total root yield of carrot had a positive correlation with root fresh weight, root dry weight, root diameter, marketable root yield, marketable root number, root dry matter content, TSS and root volume.

Table 15. Correlation analysis of phenological, growth, yield and quality parameter of carrot as influenced by the application of NPS and Boron fertilizers.

PAR	DM	PH	LN	SFW	SDW	ARW	RDW	RL	RD	MRY	UNMRY	TRY	HI	MRN	UNMRN	PDM	TSS	pH	RV
DM	1																		
PH	0.48 ***	1																	
LN	0.42 **	0.82 ***	1																
SFW	0.21 ns	0.75 ***	0.73 ***	1															
SDW	0.24 ns	0.80 ***	0.78 ***	0.95 ***	1														
ARW	0.43 **	0.88 ***	0.81 ***	0.76 ***	0.81 ***	1													
RDW	0.33 *	0.64 ***	0.51 ***	0.56 ***	0.59 ***	0.60 ***	1												
RL	0.30 *	0.76 ***	0.78 ***	0.92 ***	0.93 ***	0.80 ***	0.52 ***	1											
RD	0.35 *	0.82 ***	0.77 ***	0.92 ***	0.92 ***	0.87 ***	0.67 ***	0.89 ***	1										
MRY	0.36 **	0.68 ***	0.73 ***	0.63 ***	0.68 ***	0.63 ***	0.40 **	0.62 ***	0.63 ***	1									
UNMRY	-0.34 *	-0.68 ***	-0.68 ***	-0.69 ***	-0.75 ***	-0.64 ***	-0.38 **	-0.72 ***	-0.65 ***	-0.82 ***	1								
TRY	0.36 *	0.65 ***	0.69 ***	0.56 ***	0.62 ***	0.59 ***	0.38 **	0.55 ***	0.60 ***	0.98 ***	-0.72 ***	1							
HI	0.28 ns	0.58 ***	0.64 ***	0.68 ***	0.69 ***	0.56 ***	0.37 **	0.64 ***	0.67 ***	0.81 ***	-0.64 ***	0.81 ***	1						
MRN	0.42 **	0.72 ***	0.68 ***	0.61 ***	0.68 ***	0.62 ***	0.42 ***	0.64 ***	0.61 ***	0.78 ***	-0.77 ***	0.75 ***	0.61 ***	1					
UNMN	-0.47 ***	-0.76 ***	-0.75 ***	-0.64 ***	-0.70 ***	-0.64 ***	-0.47 ***	-0.69 ***	-0.64 ***	-0.81 ***	0.78 ***	-0.77 ***	-0.61 ***	-0.93 ***	1				
PDM	0.28 *	0.79 ***	0.77 ***	0.90 ***	0.90 ***	0.80 ***	0.72 ***	0.83 ***	0.90 ***	0.74 ***	-0.70 ***	0.70 ***	0.69 ***	0.64 ***	-0.69 ***	1			
TSS	0.12 ns	0.48 ***	0.53 ***	0.60 ***	0.60 ***	0.44 **	0.13 Ns	0.59 ***	0.50 **	0.76 ***	-0.65 ***	0.74 ***	0.74 ***	0.56 ***	-0.57 ***	0.63 ***	1		
pH	-0.36 **	-0.34 *	-0.47 ***	-0.25 ns	-0.29 *	-0.39 **	-0.37 **	-0.31 *	-0.30 *	-0.25 ns	0.27 ns	-0.21 ns	-0.12 ns	-0.29 *	0.31 *	-0.29 *	0.02 ns	1	
RV	0.34 **	0.69 ***	0.65 ***	0.51 ***	0.59 ***	0.63 ***	0.46 ***	0.53 ***	0.54 ***	0.83 ***	-0.70 ***	0.83 ***	0.60 ***	0.81 ***	-0.81 ***	0.64 ***	0.68 ***	-0.24 ***	1

Where: PAR=parameter, DM- days to maturity, PH-plant height, LN- leaf number, SFW-shoot fresh weight, SDW-shoot dry weight, ARW-average root weight, RDW- root dry weight, RL- root length, RD- root diameter, MRY-marketable root yield, UNMRY-unmarketable root yield, TRY- total root yield, HI-harvest index, MRN- marketable root number, UNMRN- unmarketable root number, PDM-percent dry matter, TSS- total soluble solid, pH- power of hydrogen ion and RV-root volume. ns= non-significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$, and *** = significant at $P \leq 0.001$.

4.7. Partial budget Analysis

The results of the partial budget analysis revealed that applying 150 kg ha^{-1} of NPS and 500ppm of Boron had the highest net benefit (1248724 Birr ha^{-1}) and MRR of 1879.22% followed by the combined application of 150 kg ha^{-1} of NPS and 250ppm Boron with a net benefit of 1170962 Birr ha^{-1} and MRR of 6234.58% (Table 16). Thus, the application of 150 kg ha^{-1} of NPS with 500 and 250ppm Boron are recommended as first and second options for carrot production in the study area.

Table 16. Summary of partial budget and marginal rate of return analysis for carrot production as influenced by NPS and B fertilizer during the main cropping season of 2022/23.

Treatments		MRY	AjMRY	TVC	GFB	NB	MRR
NPS rate (kg ha^{-1})	B rate (ppm)	(t ha^{-1})	(t ha^{-1})	(Eth-birr)	(Eth-birr)	(Eth-birr)	%
0	0	28.99	26.09	-	652275	652275	-
	250	34.59	31.13	4138	778275	774137	2944.95
	500	35.09	31.58	8276	789525	781249	D
	750	32.33	29.1	12414	727425	715011	D
75	0	36.59	32.93	4650	823275	818625	8689.06
	250	37.34	33.61	8788	840150	831362	307.81
	500	39.91	35.92	12926	897975	885049	D
	750	36.67	33.00	17064	825075	808011	D
150	0	40.99	36.90	9300	922275	912975	15940.04
	250	52.64	47.38	13438	1184400	1170962	6234.58
	500	56.28	50.65	17576	1266300	1248724	1879.22
	750	47.63	42.87	21714	1071675	1049961	D
225	0	41.96	37.76	13950	944100	930150	D
	250	49.08	44.17	18088	1104300	1086212	D
	500	46.31	41.68	22226	1041975	1019749	D
	750	42.87	38.58	26364	964575	938211	D

Where: MRY- marketable root yield; AjMRY- adjustable marketable root yield; TVC - total variable cost; GFB - growth field benefit; NB-net benefit; ETB- Ethiopian's birr; D- dominated; Selling price of carrot at farm gate = 25 Birr kg^{-1}; Purchasing costs of NPS fertilizer= 30 Eth-Birr kg^{-1}; Cost of H_3BO_3 =1400 ETB kg^{-1}; Labor cost for fertilizer application = 300 Eth-Birr Man per day.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

Carrot is the most important horticultural root vegetable crop which is cultivated in many parts of the world and also the most commonly produced as an income-generating and source of nutrition for smallholder farmers in Ethiopia. Besides its economic and nutritional importance it also plays a crucial role in medicinal uses. Carrot production is increasing from time to time mainly due to its ease of production, and the increases in small-scale rain-fed and irrigation areas. However, the production and productivity in our country is very low in according to its yield potential as compared to other countries. This low yield is primarily allied to the depletion of soil fertility due to continuous nutrient uptake of crops and inappropriate use of fertilizers which limit its production. Because of this, the experiment was conducted at Debre Berhan University, College of Agriculture and Natural Resource Sciences demonstration and research site to evaluate the effects of different rates of NPS and boron fertilizers on growth, yield, and quality of carrot (*Daucus carota* L.) during the main cropping season of 2022/23. The experiment was laid out in RCBD with three replications which consisted of four rates of NPS fertilizer (0, 75, 150 and 225 kg ha^{-1}) and four rates of Boron (0, 250, 500 and 750ppm).

The results revealed that the main effect of NPS fertilizer and Boron rate significantly influenced most of growth parameters and some yield and quality parameters. However, their interaction significantly affected most of yield and quality parameters. Of all the treatment combinations evaluated, the combined application of 150 kg ha^{-1} of NPS and 500ppm of boron rate provided higher and consistent result for different yield and quality parameters of the carrot. The widest root diameter (2.45cm), longest root length (14.98cm), highest root dry weight (19.34g), highest marketable root number (43.33), highest marketable root yield (56.28 t ha^{-1}), highest total root yield (58.68 t ha^{-1}), highest harvest index (83.67%), and highest percent dry matter content (45.7%) were produced from the combined application of 150 kg ha^{-1} of NPS and 500ppm of boron.

In addition to this, a partial budget analysis also showed that the combined application of 150 kg ha^{-1} of NPS and 500ppm of Boron rate is economically the most feasible in reducing cost of production and increase the profit gained. However, as the results were limited to one season, additional studies need to be conducted in the future at different seasons and location to give conclusive recommendation.

6. REFERENCES

Abera Jaleta Berkessa. (2020). Growth, yield and yield attributes of garlic (*Allium sativum* L.) as influenced by the interaction of varieties and rates of NPS blended fertilizer in Mettu, southwestern Ethiopia. MSc thesis

Abiti Getaneh Gebremeskel. (2011). Ethiopian Water Resource Potential and Development. Ministry of Water and Energy

Abiyot Shimels. (2008). Effect of seed bed preparation and plant density on root yield and quality of carrot (*daucus carota* l.). M. Sc. Thesis. Department of Plant Science, School of Graduate Studies, Haramaya University.

Abou EL-Yazied A., Mady M.A. (2012). Effect of boron and yeast extract foliar application on growth, pod setting and both green pod and seed yield of broad bean (*Vicia faba* L). Journal of American Science, 8(4): 517-534.

Acharya, U. R., Mishra, M., Patro, J., & Panda, M. K. (2008). Effect of vitamins C and E on spermatogenesis in mice exposed to cadmium. Reproductive toxicology, *25*(1), 84-88.

Ageless. (2009). Properties and therapeutic uses of carrots, ageless, URL: www.ageless.co.za/herb-carrot.htm.

Ahmad, Z., Ali, N., Ahmad, M., Ulhag, S., & Ahmad, S. (2005). Yield and economics of carrot production in organic farming. Sarhad. Journal of Agriculture, 21(3): 357-364.

Alemu Enkosa and Muluneh Bekele. (2019). Mineral nutrients management for carrot (*Daucus carota* L.) production: A review. International journal of food and nutrition, Zambrut, 3 (2): 48-57.

Ali, M.K., Barkotulla, M.A.B., Alam, M.N. and Tawab, K.A. (2006). Effect of nitrogen levels on yield and yield contributing characters of three varieties of carrot. Pakistan Journal of Biological Sciences, 9 (3): 553-57.

Ali, R., Khan, M.J. and Khattak, R.A. (2008). Response of rice to different sources of sulfur (S) at various levels and its residual effect on wheat in rice-wheat cropping system. Soil Environment, 27(1): 131-137.

Amandeep, K., & Simranjot K. (2021). Effect of foliar application of macro and micronutrients on growth, yield and economics of tomato (Lycopersicon esculentum Mill.) cv. NS-524. Journal of Pharmacognosy and Phytochemistry, 10(1): 2772-2775.

Anjaiah, T. and Padmaja, G. (2006). Effect of nitrogen and farmyard manure on yield and quality of carrot. J. Res. ANGRAU, 34(2): 91-93.

Arscott S.A. Tanumihardjo S.A. (2010). Carrots of many colors provide basic nutrition and bioavailable phytochemicals acting as a functional food. Comprehensive Review on Food Science and Food Safety, 9: 223-239.

Arumuganathan, K., and Earle, E. (1991). Nuclear DNA content of some important plant species. Plant Mol. Biol. Report. 9 (3), 208–218.

Asfaw. Zeleke and Eshetu. Derso. (2015). Production and Management of Major Vegetable Crops in Ethiopia, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia,

ATA (Agricultural Transformation Agency). (2016). Transforming the use of fertilizer in Ethiopia: Launching the national fertilizer blending program.

Augspole I. Rackejeva T. Kruma Z. Dimins F. (2014). Shredded carrots quality providing by treatment with Hydrogen peroxide. In LLU 9 th. Conference on "Food for Consumer Well - Being" FOODBALT. Jelgava.

Babic I, Amiot MJ, Nguyen-The C, and Aubert S. (1993). Changes in phenolic content in fresh ready-to-use shredded carrots during storage. Journal of Food Science.58:351–356.

Baniuniene, A. and Zekaite, V. (2008). The effect of mineral and organic fertilizers on potato tuber yield and quality. Lithuanian institute of agriculture's Perloja Experimental Station, Agronomijas Vēstis. Latvian Journal of Agronomy, 11:202-206.

Bartlett, H.E. and Eperjesi, F. (2008). Nutritional supplementation for type 2 diabetes: A systematic review Opht Physiolo Opt 28 503-523.

Bashour, I. I., & Sayegh, A. H. (2007). Methods of analysis for soils of arid and semi-arid regions. Food and agriculture organization of the United Nations. Rome, 119 p

Betelhem Taye.(2021). Effect of potassium chloride and cattle dung ash on growth, yield and quality of carrot (Daucus carota L.) in Debre Berhan, central highland of Ethiopia msc thesis.

Bhandari, S. A., Patel, K. S., & Nehete, D. S. (2012). Effect of integrated nutrient management on growth, yield and quality of garlic (*Allium sativum* L.) cv. Gujrat Garlic-3. Asian Journal of Horticulture, 7(1), 48-51.

Bouyoucos, G.J. (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils. Agronomy Journal. 54 (5):464-465.

Brdar-Jokanovic, M. (2020). Boron toxicity and deficiency in agricultural plants. International Journal of Molecular Sciences 21 (4):1424.

Bremner, J. M., and Mulvaney, C. S. (1982). Nitrogen - total. In: Page et al. (Eds.) Methods of soil analysis. Chemical and microbiological properties. SSSA, Madison, Wisconsin, 2: 595-642.

Broadley M., Brown P., Cakmak I., Rengel Z.z, Zhao F. (2012). Chapter 7 - Function of Nutrients: Micronutrients. In Marschner, P. ed, Marschner's Mineral Nutrition of Higher Plants (Third Edition). Academic Press, San Diego, pp, 191-248.

Bruno Ria, Viana, Js; Silva Vf; Bruno Gb; Moura Mf. (2007). Production and quality of carrot seeds and roots grown in soil with organic and mineral fertilization. Brazilian Horticulture 25: 170-174.

Bystricka, J., Kavaleova, P., Musilova, J., Vollmannova, A., Toth, T., Lenkova, M. (2015). Carrot (Daucus carota L.) Source of antioxidant. Aeta Agriculture Slovenica, 105(2):303-311.

Carneiro, L. F., A. E. Furtini Neto, A. V. Rezende, N. Curi, J. Z. L. Santos, and F. J. Lago. (2008). Sources, doses and modes of phosphorus application in the phosphorus-zinc interaction in maize. Science and Agrotechnology 32 (4): 1133–41.

Carvalho A. D.F., Silva G. O. and Magalhaes C.C. (2020). Yield and quality of carrot cultivars related to the harvest time. Horticultura Brasileira. 38: 319-323. DOI - http://dx.doi.org/10.1590/S0102-053620200313

Cecılio Filho A. B., and F. C. Peixoto. (2013). Accumulation and export of nutrients in carrot 'forto'. Caatinga Journal 26:64–70.

Chala Kitila, Abdisa Abraham and Soressa Shuma. (2022). Growth and bulb yield of some onion (*Allium cepa* L.) varieties as influenced by NPS fertilizer at Dambi Dollo University Research site, Western Ethiopia. Cogent Food & Agriculture, *8*(1), 2097606

Chen, Q.Z., XiaoSheng, Z., HongYan Wu, J., XiaoLin, L. (2003). Effects of different nitrogen application levels on growth of carrot. China Vegetables. 3(1): 4-6.

Chettri, M., Mondal, S., & Roy, B. (2002). Influence of potassium and sulphur with and without FYM on growth, productivity and diseases index of potato in soil of West Bangal. Journal of Indian Potato Association, 29(3), 61-69.

Choudhary, R. (2013). Impact of nitrogen and sulfur fertilization on yield, quality and uptake of nutrient by Maize in Southern Rajasthan. Annals of Plant and Soil Research, 15(2), 118-121.

CIMMYT (The International Maize and Wheat Improvement Center). (1988). From Agronomic Data to Farmers Recommendations: An Economics Training Manual. Completely Revised Edition. Mexico, D. F. ISBN 968-61 27-18-6

Cíntia C.A, Renato de M.P, Ancélio Ricardo de O.G, Adriana U.A, Marcus A.R, Correia. (2009). Yield and growth of sugar beet as a function of phosphorus fertilization, Scientia Agraria, Curitiba, v.10, n.1, p.075-080, Jan./Feb.

Cock JH, Voss J. (2004). A passion for fruits: Development of high value horticultural crops in Latin America. XXVI IHC: Horticulture, Art and Science for Life - The Colloquia Presentations, Acta Hort 642: 57-67.

CSA (Central Statistical Agency). (2022). Report on Farm Management Practices report on area and production of major crops (private peasant holdings, meher season) volume I, part III Ethiopian statistics service agricultural sample survey (2021/22). Federal Democratic Republic of Ethiopia, Central Statistical Authority, Addis Ababa. Statistical Bulletin 593. Pp. 19-31.

Dalbay A. (1997). Siren Feast History of Food and Gastronomy in Greece. In: Lantiquite classique pp.534-535.

Dauda SN, Ajayi FA, Ndor E. (2008). Growth and yield of water melon (Citrullus lonatus) as affected by poultry manure application. J. Agric. Soc. Sci., 4: 121-124.

Davies, J.M., Douglas, C.S., Nelson P.V., Lengnick, L., Sperry, W.I. (2003). Boron improves growth, quality and nutrient content of tomato. J. Amer. Sco. Hort. Sci.; 128 (3):441-446.

Day S., Aasim M. (2020). Role of boron in growth and development of plant: Deficiency and toxicity perspective. In: Aftab T., Hakeem K.R. (eds) Plant Micronutrients. Springer, Cham. https://doi.org/10.1007/978-3-030- 49856-6_19.

Day, P.R., (1965). Hydrometer Method of Particle Size Analysis. pp. 562-563. In C.A. Black (Ed.). Methods of Soil Analysis. Agron. Part II, No .9 Am. Soc. Agron. Madison, Wisconsin,USA.

De Pascale, S. and Barbieri, G. (2000). Yield and quality of carrot as affected by soil salinity from long-term irrigation with saline water. Acta Horticulture. 537: 621-628.

Demoz Kidanie Gebremeskel. (2016). Assessment of production practices and effect of N:P_2O_5:S rates on yield and yield components of head cabbage (*Brassica Oleracea var. capitata*) under irrigation condition in lay armachio district, amhara region, Ethiopia msc thesis.

Dias, J.C.S. (2014). Nutritional and Health Benefits of carrot and their seed extracts. Food and Nutrition Science. 5:2147-2156.

Don Eckert. (2010). Efficient Fertilizer Use of Nitrogen. Book of Nitrogen fertilizers, Pp. 1-19.

Drissi, S., A. A. Houssa, A. Bamouh, J. M. Coquant, and M. Benbella. (2015). Effect of zinc-phosphorus interaction on corn silage grown on sandy soil. Agriculture 5(4):1047–59. doi: 10.3390/agriculture5041047.

EIA (Ethiopia Investment Agency). (2012). Investment Opportunity Profile for the production of Fruits and Vegetables in Ethiopia, Addis Ababa

El-Desuki, Salman, M., El-Nemr, S.R. and Abdel-Mawgoud. (2005). Effect of plant density and nitrogen application on the growth, yield and quality of radish. Journal of Agronomy,4 (3): 225-29.

El-Dissoky R.A., Abdel-Kadar A.E.S. (2013). Eff.ect of boron as a foliar application on some potatoes cultivars under Egyptian alluvial soil conditions. Research Journal of Agriculture and Biological Sciences, 9, 232-240.

Elzer-Peters K. (2014). Midwest fruit and vegetable gardening: Plant, grow, and harvest the best edibles-Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin 136 Cool Springs Press.

Ethio-SIS, (Ethiopia Soil Fertility Status). (2016). Fertilizer Recommendation Atlas of the Southern Nations, Nationalities and Peoples' Regional State, Ethiopia, p. 81.

Fábio H.T, de Oliveira, Roberto F.N, Víctor H.Alvarez V, Reinaldo B.C. (2005). Development of a system for recommending fertilization for banana crops. Brazilian Journal of Soil Science, Viçosa, v. 29, n. 1, p. 131-143

Fageria N. K. and Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy, 88:97-185.

Fageria, N.K. and Moreira, A. (2013). Burlington: Academic Press, pp. 251-331. In Donald L. Sparks, editor: The role of mineral nutrition on root growth of crop, Vol. 110, 280- 285.

FAO (Food and Agriculture Organization). (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

FAOSTAT (Food and Agriculture Organization Statistics). (2022). Food and agriculture data access our website: https://www.fao.org/faostat/en/#home.

FAOSTAT (Food and Agriculture Organization Statistics). (2022). List of countries by carrot and turnips production.

FAOSTAT. (2015) Food and Agriculture Organization of the United Nations. URL:http://www.fao.org/statistics/en/

Federal democratic republic of Ethiopia. (2012). Ethiopia Horticulture Development Agency (EHDA)

Fekadu mariame and dandena gelmesa, (2006). Status of vegetable peroduction in ethiopia. Uganda journal of agricultural sciences, vol. 12 no.2 sept .

Flores, R. A., B. F. Almeida, L. S. Politi, R. M. Prado, and J. C. Barbosa. (2012). Growth and nutritional disorder in chilli pepper cultivated in suppressed nutrient solutions of macronutrients. Brazilian Journal of Agricultural Sciences (Agrarian) 7(1):104–10.

Fritz, V.A., (2013). Growing carrots and other root vegetables in the garden. Technical Bull. Extension Horticulturist, Department of Horticultural Science. Southern Research and Outreach Center. University of Minnesota, USA.

Furlani, A.M.C., Carvalho, C.P., Freitas, J.G., Verdial, M.F. (2003). Wheat cultivartolerance to boron deficiency and toxicity in nutrient solution. Scientia Agricola.; 60(2):359-370.

Gedefa Moreda Mijena, Andargachew Gedebo, Hussien Mohammed Beshir, Ashenafi Haile. (2022). Ensuring food security of smallholder farmers through improving productivity and nutrition of potato. Journal of Agriculture and Food Research 10 .100400,

Gerba Daba, Meseret Mulugeta, and Tarike Ayana. (2018). Effect of cattle manure on growth and yield of carrot (*DaucusCarrota* L.) under Jimma condition. Indian Journal of Agriculture Research, 52(2): 2018: 195-198.

Gerendas, J. and B. S attelmatcher, (1990). Influence of nitrogen form a nd concentration on growth and ionic balance of tomato (*Lycoperiscum esculentum*) and potato (*Solanum tuberosum*): In P lant nutration physiology and application (M.L. van Beusichem, ed).pp. 33-37. Kluuwer Academic Dordrecht.

Getacher Demissew.(2021). Effects of blended NPS fertilizer and farmyard manure on growth, yield and quality of potato (*Solanum tuberosum* L.) in debre berhan, north shewa, Ethiopia msc thesis.

Getachew Tabor and Mohammed Yesuf. (2012). Mapping Current Knowledge of Carrot Cultivation in Ethiopia. pp.1-20.

Gilani H, Shaheen F and Saeed S A .(1994). Cardiovascular actions of Daucus carota Arch Pharmacal Res 17 150-153.

Gomes, D.G., Pieretti, J.C., Rolim, W.R., Seabra, A.B., Oliveira, H.C. (2020). Advances in nano-based delivery systems of micronutrients for a greener agriculture. Advances in Nano-Fertilizers and Nano-Pesticides in Agriculture: A Smart Delivery System for Crop Improvement. https://doi.org/10.1016/B978-0-12-820092-6.00005-7.

Gomez, K.A., and A.A. Gomez .(1984). Statistical Procedures for Agricultural Research. John Willey and Sons, New York. 390 p.

Guerrera M P, Volpe S L and Mao J J .(2009). Therapeutic uses of Magnesium American Family Physician 80 157-162.

Gupta, U.C., (1993). Boron and its role in crop production. Boca Raton, FL: CRC Press, USA, pp: 53-85.

Gutezeit, B. and Gemuse, M. (2000). Effect of N fertilizer on yield and nitrate level of carrot cultivars. Muchen. 36 (12): 28-30.

Hailu Shiferaw. (2014). Digital soil mapping: Soil fertility status and fertilizer recommendation for Ethiopian agricultural land (Conference paper). Addis Ababa, Ethiopia.

Hailu, S., Seyoum, T., and Dechassa, N. (2008). Effect of combined application of organic-P and inorganic-N fertilizers on yield of carrot. African Journal of Biotechnology, 7(1),027-034.

Hansen SL, Purup S, Christensen LP. (2003). Bioactivity of falcarinol and the influence of processing and storage on its content in carrots (Daucus carota L). Journal of Science and Food Agriculture; 83:1010-1017.

Hashimoto T, Nagayama T. (2004). Chemical composition of ready-to-eat fresh carrot. J Food Hyg Soc Japan; 39:324-328.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, W.L. Nelson. (1999). Soil Fertility and Fertilizers, 6th Edition. Upper Saddle River, N.J: Prentice-Hall, Inc. 499 p.

Hazelton, P. and Murphy, B. (2007). Interpreting soil test results: what do all the numbers mean 2nd(ed). Department of natural resources. CSIRO publishing. Australia. Pp. 77-79.

Herrera-Rodriguez MB, Gonzalez-Fontes A, Rexach J, Camacho- Cristobal JJ, Maldonado JM, Navarro-Gochicao MT. (2010). Role of boron in vascular plants and response mechanism to boron stresses. Plant Stress; 4:115-122.

Hochmuth, G.J., J.D. Brecht and M.J. Bassett. (2006). Fresh-market carrot yield and quality did not respond to potassium fertilization on a sandy soil validated by Mehlich-1 soil test. Hort. Technol. 16(2): 270-276.

Horneck, D. A., Sullivan, D. M., Owen, J. S., & Hart, J. M. (2011). Soil test interpretation guide.

HU, Y.; YE, X.; SHI, L.; Duan, H. & XU, F. (2010). Genotypic differences in root morphology and phosphorus uptake kinetics in Brassica napus under low phosphorus supply. Journal of Plant Nutrition. 33:889-901.

Islam MZ, Mele MA, Choi KY, Kang HM. (2018). The effect of silicon and boron foliar application on the quality and shelf life of cherry tomatoes. Zemdirbyste-Agriculture; 105(2):159-164.

Isreal Zewide and Tamirat Lefamo. (2023). Performance of Selected Carrot Varieties as Influenced by NPS Fertilizer in North Shewa Zone, Ethiopia, Russian Agricultural Sciences, Vol. 49, No. 3, pp. 299–304.

Jansen G and Wohlmuth H. (2014). Carrot seed for contraception: A review Aust J Herbal Med 26 301-315.

Jones, Clain, Kathrin and Olson-Rutz Courtney. (2003). Pariera Dinkins nutrient uptake timing by crops to assist with fertilizing decisions, department of land resources and environmental science. Montana State University, Bozeman.

Joseph the Great Q Light, Adílio Zorzal Filho, Welisson L Rodrigues, Carlos R Rodrigues, Angelica A Queiroz. (2009b). Nitrogen, potassium and calcium topdressing in commercial carrot production. Horticultura Brasileira 27: 543-548.

Joubert TG, La G, Boelema BH, and Daiber KC. (1994). The production of carrots. Agricultural Research Council-Roodeplaat, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

Kaack, K., M. Nielsen, L.P. Christensen and K. Thorup-Kristensen. (2001). Nutritionally important chemical constituents and yield of carrot (*Daucus carota* L.) roots grown organically using ten levels of green manure, Acta Agric. Scand. Sect. B Soil Plant Sci. 51(3): 125-136.

Kandil, A.A., Attia, A.N., Badawi, M.A., Sharief, A.E. and Abido, W.A.E. (2011). Influence of water stress and organic and inorganic fertilization on quality, storability and chemical analysis of potato (*Solanum tuberosum* L). Journal of Applied Sciences Research, 7(3): 187-199.

Kassa Melese Ashebre .(2015). Opportunities and potential in Ethiopia for production of fruits and vegetables: A graduate senior seminar paper. Afr J Basic & Appl Sci 7: 328-336.

Kidmose U, Hansen SL, Christensen LP, Edelenbos M, Larsen M, Norback R. (2004). Effects of genotypes, root size, storage and processing on bioactive compounds in organically grown carrots (*Daucus carota* L). Journal of Food Science; 69:388-394.

Kim D J, Xun P, Liu K, Loria C, Yokota K, Jacobs Jr D R and He K .(2010). Magnesium intake in relation to system inflammation, insulin resistance, and the incidence of diabetes Diabetes Care 33 2604-2610.

Koley, T.K., Singh, S., Khemariya, P. (2014). Evaluation of bioactive properties of Indian carrot (*Daucus carota* L.): a chemometric approach. Food Research International, 60:76–85.

Kumawat S, Soni A, Sharma D, Soni V. (2018). Effect of organic manures and fertility levels on yield attributes of carrot (*Daucus carota* L.) ev. Pusa Rudhira. Int. J Bioinfo. and Bio. Sci; 6(5):1613-1616.

Landon, J. R. (1991). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evolution in the tropics and subtropics. Longman Scientific and Technical. Essex, New York. 474p.

Lefamo, T., Mohammed, W., and Woldetsadik, K.(2019). Effect of blended NPS fertilizer, root type and root treatment on yield and yield components of carrot (*Daucus carota* L.) seed at Haramaya, Eastern Ethiopia, J. Hortic. Sci. For, vol. 1, p. 203.

M. S. Rahman ,M. R. Hossain , A. Hossain and M. I. Khan. (2023). Impact of foliar boron application on the growth and yield of summer tomato, Journal of Agroforestry and Environment, 16(1):58-63.

Mallick MFR, Muthukrishnan CR. (1980). Effect of micro nutrients on tomato (*Lycopersicon esculentum Mill*.), II. Effect on flowering, fruit set and yield. South Indian Horticulture 28 (1), 14–20.

Mariana Vieira Nascimento, Luiz Roberto Silva Guimarães Fernandes, Ricardo Caldas Xavier, Katiane Santiago Silva Benett, Luciana Maria da Silva. (2017). Phosphate fertilization in the cultivation of root-producing vegetables. Journal of Neotropical Agriculture, Cassilândia-MS, v. 4, Supplement 1, p. 8-16, dez. ISSN 2358-6303.

Marschner H. (1995). Mineral nutrition of higher plants. 2nd Edition, Academic Press, London, 889 PP.

McPharlin, I.R., Aylmore, P.M. and Jeffery, R.C. (2012). Response of carrots (*Daucus carota* L.) to applied phosphorus leaching on a Karrakatta sand, under two irrigation regimes. Australian Journal of Experimental Agriculture, 32(2): 225 - 232.

Mehedi, T.A., Siddique, M.A. and Shahid, S.B. (2012). Effects of urea and cowdung on growth and yield of carrot. Journal of Bangladesh Agricultural University. 10 (1): 9-13.

Mehlich, "Mehlich 3 soil test extractant.(1984). A modification of Mehlich 2 extractant," Communications in Soil Science and Plant Analysis, vol. 15, no. 12, pp.1409-1416.

Mekides Mekashaw, Melkamu Alemayehu, Getachew Shumye & Amare Haileslassie. (2020). Effects of blended NPS fertilizer rates on yield and yield components of potato (*Solanum tuberosum* L.) varieties at Dessie Zuria district, Northeast Ethiopia, Cogent Food & Agriculture, 6:1, 1779478, DOI: 10.1080/23311932.2020.1779478.

Meng C, Lu X, Cao Z, HZ. (2004). Effect of sulphur fertilization on yield of rice and oil rape and the critical value of soil and available sulphur. Plant Nutrition Fertility Science; 10;218-220.

Metzger B T, Barnes D M and Reed J D. (2008). Purple carrot (*Daucus carota* L.) polyacetylenes decrease lipopolysaccharide induced expression of inûammatory proteins in macrophage and endothelial cells J Agric Food Chem 56 3554-3560.

Mikhailova, E. A., Cherney, J.H. and Cherney, D.J.R. (2003). Impact of Phosphorus from Dairy Manure and Commercial Fertilizer on Perennial Grass Forage Production. Journal of Agronomy and Crop Science, 189: 367-375.

MoANR (Ministry of Agriculture and Natural Resource). (2013). Ethiopia Is Transitioning into the Implementation of Soil Test Based Fertilizer Use System.

Mohamed Adem, C., & Wagi, F. G. P. L. (2021). Effects of blended NPS and vermicompost on bulb yield and storability of onion *(Allium cepa L.)* at haramaya, eastern Ethiopia (Doctoral dissertation, Haramaya university).

Mohammed Adem Seid. (2019). Effect of blended NPS fertilizer rates and plant spacing on growth, yield and quality of carrot of carrot (*Daucus carota* L. *subsp. Sativus*) in tehuledere district, northeastern Ethiopia msc thesis.

Moniruzzaman, M., Akand, M. H., Hossain, M. I. Sarkar, M. D. and Ullah, A. (2013). Effect of nitrogen on the growth and yield of carrot (*Daucus carota* L.). Journal of Krishi Foundation, 11(1): 76-81.

Muendo KM, Tschirley D, Weber MT. (2004). Improving Kenya’s domestic horticultural production and marketing system: current competitiveness, forces of change, and challenges for the future. Vol. 1. Tegemeo Institute of Agricultural Policy and Development.

Mulugeta Mitiku, Mosisa Chewaka, Girma Chala. (2024). Effects of NPS and Cattle Manure on Growth, Yield and Yield Components of Garlic (*Allium sativum* L.) at Guder, West Shewa

Zone, Oromia, Ethiopia. Journal of Chemical, Environmental and Biological Engineering, 8(1), 1-12. https://doi.org/10.11648/jcebe.20240801.11.

Muner, L.H., Ruiz, H.A., Venegas, V.H.A., Neves, J.C.L., Freire, F.J. and Freire, M.B.G.S. (2011). Zinc availability for maize in response to phosphorus localization in soil. Brazilian Journal of Agricultural and Environmental Engineering, 15, 29-36. http://dx.doi.org/10.1590/S1415-43662011000100005.

Murphy HF. (1968). A Report on the Fertility Status of Some Soils of Ethiopia. Experimental Bull. No. 1. Imperial College of Agriculture and Mechanical Arts; Alemaya, Ethiopia, 201 p.

Nahar, N. Mazed, M.K., Moonmoon, J.F., Mehraj, H. and Jamal Uddin A.F.M. (2014). Growth and Yield Response of Carrot (*Daucus carota* L.) to Phosphorus. Int. J. Bus Soc Res 01(02):125-128.

Nardos, M. W. (2021). Effect of NPS fertilizer rates on yield and yield components of tomato (*lycopersicon esculentum* mill) varieties at ginchi, central high land of west shoa zone of Oromia, Ethiopia (Doctoral dissertation, Ambo University).

Nayeem K, Godad A, Hashilkar N and Joshi R .(2010). Gastroprotective activity of the aqueous extract from the roots of Daucus carota L in rats IJRAP 1 112-119.

Naz RMM, Muhammad S, Hamid A, Bibi F. (2012). Effect of boron on the flowering and fruiting of tomato. Sarhad Journal of Agriculture 28(1), 37–40.

Nunes, M.C.N. and Emond, J.P. (1999). Chlorinated water treatments affect postharvest quality of green bell peppers. Journal of Food quality. 22: 353-361.

Olsen, S., Cole, F., Watanabe, D. and Dean, A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. Agric. Circ.939, 19 USA.

Oosterhuis DM, Weir BL. (2010). Foliar fertilization of cotton. In: J. M. D. Stewart (Eds.), Physiology of Cotton. Springer Science + Business Media B.V; 272–288.

Osono, T. and Takeda, H. (2005). Decomposition of organic chemical components in relation to nitrogen dynamics in leaf litter of 14 tree species in a cool temperate forest. Ecol Res., 20: 41-49.

Pandav AK, Nalla MK, Aslam T, Rana MK, Bommesh JC. (2016). Effect of foliar application of micronutrients on growth and yield parameters in Eggplant cv HLB 12. Environment and Ecology; 35(3):1745-1748.

Patil M V K, Kandhare A D and Bhise S D .(2012). Antiinflammatory effect of Daucus carota root on experimental colitis in rats Int J Pharm Pharm Sci 4 337-343.

Plunkett, G. M., Pimenov, M. G., Reduron, J.-P., Kljuykov, E. V., van Wyk, B.-E., Ostroumova, T. A., Muckensturm, B. (2018). Apiaceae. Flowering Plants. Eudicots, *9–206*.

Rani N.S and Mallareddy K. (2006). Effect of different organic manures and inorganic fertilizers on growth, yield and quality of carrot. Karnataka Journal Agricultural Science 20(3): 686-688.

Rani, S.N. and Mallareddy, K. (2007). Effect of different organic manures and inorganic fertilizers on growth, yield and quality of carrot (*Daucus carota* L.) Karnataka Journal of Agricultural Sciences, 20(3): 686-88.

Rehman, A., M. Farooq, Z. Ata Cheema, A. Nawaz, and A. Wahid. (2014). Foliage applied boron improves the panicle fertility, yield and biofortification of fine grain aromatic rice. Journal of Soil Science and Plant Nutrition 14 (3):723–33. doi:10.4067/s0718-95162014005000058.

Rice, R. Rice, L., W and Tindall, H.O .(1987). Fruits and vegetables in the tropics. Macmillan publisher. pp. 249-251.

Rose. Kennedy. (2021). No peeling required: how to grow nantes carrots.

Rubatzky VE, Quiros CF, and Simon PW. (1999). Carrots and Related Vegetable Umbelliferae. Wallingford, CT: CAB International, pp. 2–9.

Ryan J, Estefan G. Rashid A. (2001). Soil and Plant Analysis Laboratory Manual, p: 172. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Ryan, J. (2002). Available soil nutrients and fertilizer use in relation to crop production in the Mediterranean area. In: K. R. Krishna (ed) Soil fertility and crop production. Science Publishers, Inc., Enfield, New Hampshire, USA.

Sadia, A.A., Mahasen, M., Shahrin, S., Roni, M.Z.K. and Jamal, A.F.M.U. (2013). Phosphorus levels on growth and yield of turnip (*Brassica campestris var. rapifera*). Bangladesh Research Publications Journal, 8 (1): 29-33.

Salim B.B.M., Abd El-Gawad H.G., Abou ElYazied A., Hikal M.S. (2019). Effect of Calcium and Boron on Growth, Fruit Setting and Yield of Hot Pepper (*Capsicum annuum* L.). Egypt. J. Hort., 46, 1, 53-62.

Salim, B.B.M., N. M. Taha, A. Abou El-Yazied.(2022). Stimulating the growth, storage root yield and quality of carrot plants by phosphoric acid, potassium and boric acid foliar applications. Scientific Journal of Agricultural Sciences 4 (1): 0-0.

Salo, T. (2000). N uptake by cabbage, carrot and onion: Quality management of fruits and vegetables from field to table Agri-Food Quality II. Conference paper. 57-59.

SAS, Institute Inc. (2012). SAS/STAT User"s Guide, SAS Online document 9.31, Cary, NC: SAS Institute, Inc.

Shaimaa Abd El-Hameed Abo-Hamad and Soad Soliman El-Feky. (2014). Effect of Boron on Growth and Some Physiological Activities of Tomato Plant. Life Science Journal; 11(7).

Shanmugasundaram, R. and Savithri, P. (2002). Impact of nitrogen with organics on quality attributes and yield of carrot root (*Daucus carota* L.). Advances in Plant Sciences.15 (2):637-39.

Shanu, V. Lakshminarayana, D. Prasanth, P. and Saida D. (2019). Studies on the Effect of Integrated Nutrient Management (INM) on Growth and Yield Parameters of Carrot (*Daucas carota* L.) cv. Kuroda Improved under Southern Telangana Conditions. International .Journal of Current Microbiology Applied Science, 8 (4): 2786-2791.

Sharma D. (2015). Effect of Sulphur on Growth, Yield and Economic of Potato Cultivar. Annals of Plant and Soil Research, 17 (1): 45-49.

Shoaib Rahman.(2021). Influence of nitrogen and sulphur on growth and yield of carrot. msc thesis.

Siddiky MA, Halder NK, Ahammad KU, Anam K, Rafiuddin M. (2007). Response of brinjal to zinc and boron fertilization. Int. J. Sustain. Agric. Technol;3:40-45.

Silva, L., P. E. R. Marchiori, C. P. Maciel, E. C. Machado, and R. V. Ribeiro. (2010). Photosynthesis, water relations and growth of young coffee trees in relation to the availability of phosphorus. Agricultural Research in Brazil 45: 965–72. doi: 10.1590/S0100-204X2010000900005.

Singh D.P., Beloy J., McInerney J.K., Day L. (2012). Impact of boron, calcium and genetic factors on vitamin C, carotenoids, phenolic acids, anthocyanins and antioxidant capacity of carrots (*Daucus carota*). Food Chemistry, 132.

Singh, D.P., Singh, H., Ali, J. and Singh, S.P. (2016). Productivity, profitability and nutrient uptake in carrot (*Daucus carota*) and radish (*Raphanus sativus*) crops under sulphur nutrient. JOUR., 86: 1577-1580.

Sisay Hailu, Tilahun Seyoum and Nigussie Dechassa. (2008). Effect of combined application of organic P and inorganic N fertilizers on post harvest quality of carrot. African Journal of Biotechnology, 7(13), pp. 2187-2196, 4. ISSN 1684-5315.

Souri, M. K., and M. Bakhtiarizade. (2019). Biostimulation effects of Rosemary essential oil on growth and nutrition uptake of tomato seedlings. Scientia Horticulture 243:472476.

Spooner, D.M. (2019). Daucus: Taxonomy, Phylogeny, Distribution. In: The Carrot Genome, Compendium of Plant Genomes (Simon et al., Eds). Springer Nature Switzerland AG, Cham, Switzerland, pp 9-26.

Stanic G, Samarzija I and Blazevic N .(1998). Time-dependent diuretic response in rats treated with Juniper berry preparations Phytother Res 12 494-497.

Stewart MW, Dibb, Johnston EA, Syth JT .(2005). The contribution of commercial fertilizer nutrients to food production. Agron. J., 97: 1-6.

Stokes D, Stokes L. (1985). A guide to enjoying wildflowers. Boston, USA: Little, Brown and Company.

Sultana S, Muhmood A, Shah SSH, Saleem I, Niaz A, Ahmed ZA.(2015). Boron Uptake, Yield and Quality of Carrot (*Daucus carota* L.) In Response to Boron Application International Journal of Plant & Soil Science.; 8(5):1-5. Article no. IJPSS.19667 ISSN: 2320- 7035

Tandon HLS, Messick DL. (2007). Practical sulphur guide (revised) The Sulphur Institute, Washington, DC; c.

Tariq Aftab, K.R.H. (2020). Plant Micronutrients: Deficiency and Toxicity Management. Springer.

Tekalign Taddese. (1991). Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Tersahima, I. and J.R. Evans. (1988). Effect of light and nitrogen nutrition on the organization of the photosynthetic apparatus in spinach. Plant Cell Physiol., 29: 143-155.

Tindall,H.O. (1983).Veagtables in the tropics.Macmillan Endication.Basing store,Hampshire and London,Britain,pp440-530.

Tohidloo, G., and M. K. Souri. (2009). Uptake and translocation of boron in two different tomato (*Lycopersicon esculentum Mill*) genotypes. Horticulture Environment and Biotechnology 50 (6):487–91.

Uchida R. (2000). Essential nutrients for plant growth: Nutrient functions and deficiency symptoms. from: plant nutrient management in Hawaii's soils, approaches for tropical and subtropical agriculture, J. A. Silva and R. Uchida, eds. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

USDA National Nutrient Database for Standard Reference. (2014). Composition of Foods Raw, Processed, Prepared. Available from: http://www.nal.usda.gov/fnic/foodcomp/search/. Accessed June 20, 2014.

USSLS (United States Salinity Laboratory Staff). (1954). Diagnosis and improvement of saline and alkali soils. USDA Agri. Handbook. No. 60. 160 p.

Van Reeuwijk, L. P. (1993). Procedure for Soil Analysis. 4th Edn. International Soil Reference Center Wageningen (ISRIC) Technical Paper No. 9. The Netherlands.Volume 3 Number 7 (2014) pp. 874-881.

Vasudevan M, Milind P, Kalavathy R,Abu B and Abdul M .(2010). Anti-dementia potential of Daucus carota seed extract in rats Pharmacology online 1 552-565.

Wafaa, H.M. (2013). Yield, quality and micronutrients uptake of carrot (*Daucus carota* L.) and some soil properties as affected by organic fertilizers and elemental sulphur application. Egypt J. Soil Sci., 53(4): 537-554.

Walkley, A.J. and Black, I.A. (1934). Estimation of Soil Organic Carbon by the chronic acid Titration method. Soil Science 37: 29-38.

Wawrzyńska, A., and Sirko, A. (2014). To control and to be controlled: understanding the Arabidopsis SLIM1 function in sulfur deficiency through comprehensive investigation of the EIL protein family. Front. Plant Sci. 5:575. doi: 10.3389/fpls.2014.00575.

White J., Wheatley E., Hammond P. and Zhang K. (2007). Minerals, soils and roots. In: Vreugdenhil D (ed.), Potato biology and biotechnology, advances and perspectives. Elsevier, Amsterdam, p 739-752.

Win L.L. (2010). Agronomic characteristics and nutritional quality of carrot (*Daucus carota* L.) Cultivars from Myanmar and Germany as affected by mineral and organic fertilizers. PhD thesis, faculty of agricultural science, George -Augest University Gottingen. Germany.

Yadav LM, Singh YP, Kumar J, Prasad SS, Mishra AK. (2018). Response of zinc and boron application on yield, yield parameters and storage quality of garlic (*Allium sativum* L.) var. G-282. Journal of Pharmacognosy and Phytochemistry; 7(1):1768-1770.

Zaini R G, Brandt K, Clench M R and Le Maitre C L .(2012). Effects of bioactive compounds from carrots (*Daucus carota* L.), polyacetylenes, beta-carotene and lutein on human lymphoid leukaemia cells Anticancer Agents Med Chem 12 640-652.

Zhao F.J., Hawkesford M.J., McGrath S.P. (1999). Sulphur assimilation and effects on yield and quality of wheat. Journal of Cereal Sciences, 30: 1-17.

7. APPENDICES

Appendix Table 1. Mean square from analysis of variance (ANOVA) for days to maturity, plant height, leaf number, shoot fresh and dry weight of carrot as influenced by NPS and Boron fertilizer.

Source of variation	DF	DM	PH	LN	SFW	SDW
Rep	2	635.73 *	7.16 ns	1.37 *	41.23 ***	12.5 ***
NPS	3	1579.34 **	776.44 ***	50.28 ***	140.99 ***	68.58 ***
Boron	3	73.20 Ns	128.42 ***	13.04 ***	323.53 ***	97.19 ***
NPS x B	9	13.16 Ns	8.95 ns	0.64 ns	2.93 Ns	0.45 ns
Error	30	239.72	5.72	1.9	1.4	0.59
CV (%)		9.72	8.66	13.35	4.5	6.17

Where: - DF - degree of freedom, DM - days to maturity, PH - plant height, LN - leaf number, SFW– shoot fresh weight, SDW – shoot dry weight

Appendix Table 2 Mean square from analysis of variance (ANOVA) for average root weight, root dry weight, root length and diameter of carrot as influenced by NPS and Boron fertilizer.

Source of variation	DF	ARW	RDW	RL	RD
Rep	2	437.20 **	12.99 ***	6.28 ***	0.04 *
NPS	3	4109.48 ***	65.47 ***	22.04 ***	0.25 ***
Boron	3	1401.81 ***	66.53 ***	33.99 ***	0.63 ***
NPS x B	9	96.56 Ns	2.43 ***	0.83 **	0.03 **
Error	30	56.88	0.57	0.27	0.01
CV (%)		10.23	5.63	4.49	4.23

Where: - DF - degree of freedom, ARW – average root weight, RDW – root dry weight, RL – root length, RD– root diameter.

Appendix Table 3. Mean square from analysis of variance (ANOVA) for marketable root yield, unmarketable root yield, total root yield, marketable and unmarketable root number, harvest index of carrot as influenced by NPS and Boron fertilizers

Source of variation	DF	MRY	UNMRY	TRY	HI	MRN	UNMRN
Rep	2	1.94 Ns	2.56 ns	14.84 ns	1.11 ns	2.35 ns	0.4 ns
NPS	3	664.19 ***	48.62 ***	386.46 ***	87.49 ***	515.01 ***	515.16 ***
Boron	3	133.54 ***	9.34 ***	74.94 ***	71.67 ***	44.80 ***	44.78 ***
NPS x B	9	20.21 *	3.18 **	14.23 *	19.61 **	7.06 *	7.08 **
Error	30	9.03	0.82	6.36	5.56	7.01	13.48
CV (%)		7.29	13.77	5.36	3.12	7.33	10.11

Where: - DF **-** degree of freedom, MRY– marketable root yield, UNMRY – unmarketable root yield, TRY – total root yield, MRN– marketable root number, UNMRN – unmarketable root number, HI – harvest index.

Appendix Table 4. Mean square from analysis of variance (ANOVA) for percent dry matter content, total soluble solids, PH and root volume of carrot as influenced by NPS and Boron fertilizers

Source of variation	DF	PDMC	TSS	pH	RV
Rep	2	17.03 *	4.50 Ns	0.81 **	66.25 Ns
NPS	3	213.83 ***	75.53 ***	0.42 *	2839.52 ***
Boron	3	247.37 ***	39.93 ***	0.04 ns	55.32 Ns
NPS x B	9	11.12 ***	2.34 Ns	0.02 ns	13.41 Ns
Error	30	1.99	3.09	0.16	48.90
CV (%)		3.96	16.94	5.74	8.46

Where: - DF - degree of freedom, PDMC – percent dry matter content, TSS – total soluble solids, pH– power of hydrogen ion, RV– root volume.

Appendix Table 5. Effect of NPS and Boron fertilizers on root dry weight, root length, root diameter, marketable and unmarketable root yield of carrot

NPS rate (kg ha^{-1})	RDW	RL	RD	MRY	UNMRY
0	10.75^{d}	9.77^{d}	1.91^{c}	32.75^{d}	8.17^{a}
75	12.20^{c}	11.26^{c}	2.10^{b}	37.63^{c}	6.28^{b}
150	15.92^{a}	12.18^{b}	2.23^{a}	49.39^{a}	4.05^{d}
225	14.63^{b}	12.91^{a}	2.19^{a}	45.06^{b}	4.92^{c}
Significance level	***	***	***	***	***
B rate (ppm)					
0	10.23^{d}	9.47^{b}	1.78^{c}	37.14^{b}	7.01^{a}
250	13.22^{c}	11.08^{c}	2.13^{b}	43.41^{a}	5.58^{bc}
500	15.81^{a}	13.47^{a}	2.32^{a}	44.40^{a}	4.92^{c}
750	14.23^{b}	12.09^{b}	2.19^{b}	39.88^{b}	5.90^{b}
Significance level	***	***	***	***	***
CV(%)	7.46	5.06	5.53	8.27	16.77

Where- RDW- root dry weight, RL- root length, RD- root diameter, MRY- marketable root yield, UNMRY- unmarketable root yield

Appendix Table 6. Effect of NPS and Boron fertilizers on total root yield, harvest index, marketable root number, unmarketable root number and percent dry matter content of carrot

NPS rate (kg ha^{-1})	TRY	HI	MRN	UNMRN	PDM
0	40.92^{d}	72.11^{b}	27.00^{c}	23^{a}	31.09^{c}
75	43.95^{c}	74.50^{b}	35.83^{b}	14.17^{b}	33.19^{b}
150	53.44^{a}	77.67^{a}	41.33^{a}	8.67^{c}	39.49^{a}
225	49.97^{b}	77.67^{a}	40.4^{a}	9.6^{c}	39.09^{a}
Significance level	***	***	***	***	***
B rate (ppm)					
0	44.19^{b}	72.11^{b}	34.00^{c}	16.00^{a}	29.83^{d}
250	48.99^{a}	76.25^{a}	36.75^{ab}	13.25^{b}	34.74^{c}
500	49.32^{a}	77.92^{a}	38.5^{a}	11.50^{c}	40.32^{a}
750	45.78^{b}	75.67^{a}	35.32^{bc}	14.68^{ab}	37.96^{b}
Significance level	***	***	***	***	***
CV(%)	6.07	3.93	7.33	12.80	5.91

Where- TRY- total root yield, HI- harvest index, MRN- marketable root number, UNMRN- unmarketable root number, PDM- percent dry matter content