STUDIES ON THE EFFECT OF MICRONUTRIENTS ON SEED YIELD, QUALITY AND NUTRIENT UPTAKE IN TURNIP

Thesis

by

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submitted to

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CERTIFICATE-I

This is to certify that the thesis titled, **"Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip"**, submitted in partial fulfilment of the requirements for the award of the degree of Master of Science (Agriculture) Seed Science and Technology in the discipline of **Plant Sciences** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) - 173 230 is a bonafide research work carried out by **Mr Prashant Panghal (H-2020-85-M)** son of Mr Ramesh Kumar under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Dr Rajender Sharma
Major Advisor

Place: Nauni (Solan)
Dated:

CERTIFICATE-II

This is to certify that the thesis titled, **"Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip"**, submitted by **Mr Prashant Panghal (H-2020-85-M)** son of Shri Ramesh Kumar to the Dr Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP)-173 230 India in partial fulfilment of the requirements for the degree of Master of Science (Agriculture) Seed Science and Technology in the discipline of **Plant Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Needless to say Errors and Omissions are mine.

Place: Nauni, Solan
Dated :___/___/ 2023 **(Prashant Panghal)**

CONTENTS

ABBREVIATIONS USED

%	:	Per cent
&	:	And
/	:	Per
@	:	At the rate
+	:	Plus
=	:	Equal to
×	:	Multiplication
ANOVA	:	Analysis of Variance
cm	:	Centimetre
cm^2	:	Square centimetre
cv.	:	Cultivar
df	:	Degree of freedom
CD	:	Critical Difference
CRD	:	Completely Randomized Design
DAT	:	Days after transplanting
$dS\ m^{-1}$	:	Decisiemens per metre
ed.	:	Edition
eds.	:	Editors
et al.	:	Co-workers
etc.	:	Et cetera
F-cal	:	F-calculated
g	:	Gram
i.e.	:	That is
l^{-1}	:	Per litre
kg	:	Kilogram
Mn	:	Manganese
$MnSO_4$	:	Manganese sulphate
mg	:	Milligram
ml	:	Millilitre
mm	:	Millimeter
$^{\circ}C$	:	Degree Celsius
ppm	:	Parts per million
q	:	Quintals

RBD	:	Randomized Block Design
RH	:	Relative Humidity
SE	:	Standard Error
SVI-I	:	Seed vigour index-I
SVI-II	:	Seed vigour index-II
var.	:	Variety
viz.	:	Videlicet (namely)
Zn	:	Zinc
$ZnSO_4$	:	Zinc sulphate

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Chapter-1

INTRODUCTION

Turnip (*Brassica rapa* L.) is a root crop of the Brassicaceae (Cruciferae) family. It is a popular vegetable crop farmed all the year round in various sections of the country. The turnip has a long history that precedes human civilization. It's said to have come from Central and Western China, as well as Middle Asia and the Mediterranean region (Choudhary, 1967). It is a key nutritional component in human cuisine, whether as a fresh salad or a cooked vegetable. Each 100 g edible weight of roots includes 41.6 per cent moisture, 6.2 g carbohydrates, 0.5 g protein, 0.2 g fat, 43 mg ascorbic acid, 30 mg calcium, 40 mg phosphorus, 0.4 mg iron and 1.5669 global units of vitamin A (Chatfield, 1949).

The crop is widely grown in Haryana, Bihar, Tamil Nadu, Punjab, and Himachal Pradesh in India. Turnip has a large number of cultivars when it comes to seed production. There are two types of turnip cultivars: Asiatic or tropical varieties and European or temperate ones. Asiatic kinds produce seeds across the plains of India. Seed of temperate varieties is produced in temperate areas of the country, such as the Kashmir valley and Kullu and Kinnaur districts of Himachal Pradesh. Seed of temperate turnip cultivar such as the Purple Top White Globe is produced in large quantities in Himachal Pradesh. In Himachal Pradesh, the total land area under root crops (turnip, radish and carrot) is around 960 hectares, with an annual yield of approximately 16000 metric tonnes (Verma and Goma, 2000).

Turnip leaves are typically light green, slender and hairy. At the base of the leaf petioles, a white-fleshed big global or tapering root emerges. Flowering stems with branches are also generated. The blooms are generally grown above the terminal buds and are grouped at the apex of the raceme.

Micronutrients are necessary plant nutrients that are utilized in smaller amounts than other basic plant nutrients. They are critical for germination, plant development, yield and quality. Plant development is impeded when micronutrients are deficient. As a result, these elements are often known as trace or minor elements. However, the word micronutrient is preferred. Micronutrients are becoming increasingly important in vegetable crops due to their nutritional benefits. Despite the fact that micronutrient requirements are minimal, their shortage might limit growth and productivity (Anuprita *et al.*, 2005).

Zinc is an essential element for normal plant growth and development, and it is found in a variety of foods. After nitrogen, phosphorus and potassium, zinc is the fourth most major yield-limiting nutrient. An analysis of 256,000 soil samples and 25,000 plant samples from throughout India revealed that 48.5 per cent of soils and 44 per cent of plant samples were zinc deficient, making zinc insufficiency the most frequent micronutrient deficit influencing agricultural output in the country. Zinc deficiency has become more common in southern areas as a result of the widespread use of NPK fertilizers that lack micronutrients. Periodic analysis of soil test data also reveals that zinc deficiency in Indian soils is anticipated to rise from 49 to 63 per cent by 2025, as most marginal soils brought under cultivation are showing zinc deficiency (Singh, 2009).

Zinc influences the activities of hydrogenase and carbonic anhydrase, as well as the stability of ribosomal fractions and the production of cytochrome (Tisdale *et al*., 1984). Plant enzymes triggered by Zn are involved in glucose metabolism, cellular membrane integrity, protein synthesis, auxin production control and pollen development (Marschner, 1995). Zn is necessary for the control and maintenance of gene expression required for plant abiotic stress tolerance (Cakmak, 2000). Its insufficiency causes anomalies in plants, which manifest as deficient signs such stunted growth, chlorosis and reduced leaves, as well as spikelet sterility. Zinc deficiency can also alter the quality of harvested goods; increase the vulnerability of plants to harm caused by strong light or temperature intensity and makes them more susceptible to fungal infections. (Marschner, 1995 and Cakmak, 2000). Zinc is necessary for the synthesis of tryptophan, which in turn is a precursor to IAA and it also plays a role in the creation of auxin, a vital growth hormone. Zn is necessary for cellular membrane integrity in order to keep macromolecules and ion transport systems in their structural orientation. Its interaction with phospholipids and the sulphydryl groups of membrane proteins helps to keep membranes in good shape.

Plethora of research proved that manganese is essential for the creation of chlorophyll, respiration and nitrate absorption in plants. It also stimulates enzymes that create amino acids, which are primarily used in protein building and plant stress responses. It also plays a function in hormone regulation (IAA) and can cause plants to blossom early. Manganese is required for a variety of photosynthetic oxidation and reduction processes (Nijjar, 1990).

Manganese deficiency appears as a patchy fading of the leaf on immature leaves. Veins remain green, while interveinal regions become light green to yellow. White patches might also be detected between veins in severe circumstances. To address any shortfall, Mn foliar sprays with zinc are commonly used. Mn and Zn interact strongly; plants lacking in Mn will have high Zn levels, and vice versa. Manganese shortage has a negative impact on cropping, growth and yield. Photosynthesis, effective nitrogen usage, protein metabolism and enzyme activation all require manganese. In deficient trees, both soil treatment and foliar sprays boost yields. This is due to an increase in the amount of fruits per tree. Furthermore, foliar applications of Zn and Mn, either alone or in combination, resulted in a considerable increase in sweet orange fruit output (Tariq *et al*., 2007).

Among the several agronomic manipulations to boost the yield, use of micronutrients is crucial. Numerous studies have proven a beneficial response to full foliar nutrition in major agronomic crops (Ahmed and Ahmed, 2005).

Foliar application is one of the simplest and most successful strategies for delivering required nutrients to plants in suitable concentrations, improving plant nutritional status and increasing crop production and quality. Crops need all of the important micronutrients, such as ammonium molybdate, boron, zinc, copper, iron and magnesium which are seldom provided to soils. Foliar application may thus be a potential strategy for increasing crop growth and output.

Foliar administration of micronutrients has a benefit over soil treatment in that nutrients are delivered and absorbed directly by the target organs resulting in a faster response. It is a strategy for supplying nutrients to higher plants quickly and increasing plant nutrient absorption. The advantage of foliar treatment is that it helps plants to ingest nutrients much faster than their roots can absorb them from the soil. They are an essential component of the enzyme system and are involved in the production of chlorophyll, protein synthesis and as an oxidation-reduction agent in biological systems (Kaya and Higgs, 2002).

Keeping in view all the above-mentioned facts, the present research entitled, **“Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip”** has been carried out with the following objectives:

1. To study the effect of foliar application of micronutrients on seed yield, quality and nutrient uptake in turnip
2. To study the effect of foliar application of micronutrients on nutrient content (Zn and Mn) in above ground plant parts and seed

Chapter-2

REVIEW OF LITERATURE

Before starting any scientific investigation, it is necessary to scan the available literature relevant to the problem. The literature pertaining to the effect of micronutrients on seed yield, quality and nutrient uptake in turnip (*Brassica rapa* L.) is scanty. Therefore, the relevant literature available on various aspects of present study on other vegetable crops has also been reviewed under the following heads:

2.1 : Effect on root crops

Deepika and Pitagi (2015) conducted an experiment at Bangalore during Kharif, 2013 wherein four levels of nutrients (M_1: 75:40:40 NPK kg ha^{-}1, M_2: RDF+$ZnSO_4$ @10 kg ha^{-1}, M_3: RDF + Borax @ 0.1% and M_4: RDF + $ZnSO_4$ @ 10 kg ha^{-1} + Borax @ 0.1%) were sprayed at bud initiation stage. The results showed that foliar spray of M_4 was effective in maximizing plant height, number of leaves plant^{-1}, siliquae count plant^{-1}, siliqua weight and siliqua length of radish.

Sharma (2019) investigated the effect of zinc sulphate (0, 1, 2, 3 g l^{-1}) at bolting stage, 14 days after bolting and 28 days after bolting applied through foliar sprays on radish. She observed that all the seed yield and quality traits were enhanced by $ZnSO_4$ @ 2 g l^{-1} applied at bolting.

Santhosha *et al*. (2022) in their studies combined seven levels of zinc, iron, magnesium, copper and boron with two levels of spray schedules *i.e.*, 30 and 45 days after sowing. They concluded that foliar application of nutrients (Zn, Fe, Mg each @ 0.5 % + copper @ 0.2 % + boron @ 0.5 %) 45 days after sowing significantly increased plant height, fresh weight of leaves, gross return and benefit cost ratio in carrot.

2.2 : Effect on other vegetable crops

Sayed *et al*. (2007) applied zinc sulphate and manganese sulphate both @ 0, 2, 4 and 8 ppt before 10 days and after 20 days of flowering in potato. They reported that foliar application of $ZnSO_4$ @ 8 ppt + $MnSO_4$ @ 4 ppt increased the number of tubers plant^{-1}, tuber weight and yield.

Patil *et al*. (2008) conducted an experiment to investigate the effect of foliar spray of micronutrients on growth and yield of tomato (cv. Megha). Foliar sprays were given at three stages of development *i.e.,* 40, 50 and 60 DAT. The findings showed that applying combination of micronutrients [(Bo, Zn, Mn and Fe) @ 100 ppm and Mo @ 50 ppm] produced a higher fruit yield.

Nandi and Nayak (2008) in their field experiment sprayed zinc, manganese, copper and iron @ 100 ppm and molybdenum @ 50 ppm individually as well as in combination. Mixture of all the nutrients sprayed thrice at 10-day intervals starting from 40 days after transplanting led to the highest total yield, head weight, net income and benefit: cost ratio in cabbage.

Said-Al Ahl and Omer (2009) applied chelated zinc (0, 200 and 400 ppm) and chelated iron (0, 200 and 400 ppm) as foliar sprays after 60, 90 and 120 days sowing in coriander. They reported that coriander plants sprayed during the vegetative and flowering stages with 400 ppm zinc + 200 ppm iron produced the highest fresh herb yield.

Nadergoli *et al*. (2011) investigated the impact of zinc sulphate and manganese sulphate following different methods and times of application comprising the treatments *viz.* control, soil application, foliar application at the shooting stage, flowering stage, podding stage, shooting and flowering stages, shooting and podding stages, flowering and podding stages and shooting, flowering and podding stages in common bean. They opined that the results would be better if the foliar application included both at vegetative and reproductive stages.

Pandurang (2011) conducted an investigation at Latur (Maharashtra) with sweet pepper involving foliar application of zinc sulphate at flowering initiation, 15 days after flowering and 30 days after flowering. He recorded maximum fruit diameter, maximum yield, number of seeds fruit^{-1} and weight of seed fruit^{-1} by administering zinc sulphate @ 5 g l^{-1}.

Kumari (2012) investigated the effects of foliar application of boron, zinc, molybdenum, copper, iron, manganese individually and mixture of all along with multiplex on the quality of tomato fruit and seed. The crop was sprayed thrice at 10 days intervals starting from 30 days after transplanting with 100 ppm of each. Boron showed the greatest increase in seedling length and application of copper and zinc increased the total soluble solids, vitamin C and lycopene content of the fruit.

Yousefi and Zandi (2012) conducted a study on pumpkin during 2011 at Qazvin Iran comprising treatments namely, control, $ZnSO_4$, $MnSO_4$ and Zn + Mn. They observed that four combined foliar applications (Zn + Mn @ 3000 ppm) at the blossoming stage remarkably increased the fruit yield, seed yield and oil.

Chanchan *et al*. (2013) investigated the effect of four micronutrients namely Zn (0.10, 0.25 and 0.50 %), Mn (0.10, 0.25 and 0.50 %), B (0.1, 0.2 and 0.3 %) and Fe (0.1, 0.2 and 0.3 %) sprayed on garlic at 45, 60 and 75 days after planting. They found that foliar application of borax at 0.2 % resulted in maximum leaf number, clove number, bulb weight and yield and was followed by $ZnSO_4$@ 0.25 %.

Devi *et al*. (2013) tested three different levels (0.25, 0.5, and 0.75 %) of $ZnSO_4$ in chilli applied at flower bud initiation stage and 20 days after first application. They discovered that 0.75 percent level resulted in maximum plant height, stem diameter, fruit length and number of seeds fruit^{-1}.

Naga *et al*. (2013) investigated the effect of boron, zinc, molybdenum, copper, iron, manganese and a combination of all of these elements in tomato. All the micronutrients were sprayed thrice @100 ppm except for manganese @ 50 ppm at ten days interval beginning 30 days after transplanting. The use of all the micronutrients in a mixture form resulted in the highest plant height, number of primary branches, compound leaves, fruits plant^{-1} along with total yield in both the varieties Utkal Kumari and Utkal Raja.

Pandey *et al*. (2013) conducted an experiment to find out the optimal growing phase and concentration of zinc for higher seed yield and quality in pea. Zn (0.01, 0.10 and 0.5 % $ZnSO_4$) was administered as foliar treatment. They noticed a substantial increase in yield characteristics such as number of flowers, number of pods, pod size and number of seeds with $ZnSO_4$ @ 0.5 % applied at bud initiation stage.

Yadav *et al*. (2014) investigated the influence of different levels of nitrogen (0, 1.0, 1.5 and 2.0 %) and zinc (0, 20, 30 and 40 ppm) as foliar sprays in cauliflower. They arrived at the conclusion that two foliar sprays of zinc sulphate @ 40 ppm at 30 and 45 days after transplanting registered maximum plant height, plant spread, curd weight and yield.

Al-Jobori and Al-Hadithy (2014) sprayed zinc, manganese, copper and iron in potato at half and full concentrations along with no spray as control. Sprays were administered 10 days before, during and 20 days after flowering. It was found that treatment combination involving $ZnSO_4$ @ 330 g + $MnSO_4$ @ 330 g + $FeSO_4$ @ 150 g + $CuSO_4$ @ 80 g dissolved in 1000 litre water sprayed at full concentration during flowering increased the number of tubers plant^{-1}, yield and per cent dry matter.

Mehraj *et al*. (2015) tested foliar application of six micronutrients (Zn, B, Fe, Cu, Mo and Mn) mixture on okra @ 100 ppm. The treatments were coded as M_1: control (fresh water spray), M_2: one foliar application 20 DAS and M_3: two foliar applications at 20 and 35 DAS. They observed that foliar feeding of micronutrients mixture M_3 increased the growth and yield of okra.

Acharya *et al*. (2015) conducted a study on multiplier onion in Tamil Nadu comprising combinations of micronutrients zinc and boron applied as basal dose (5 and 10 kg ha^{-1}) as well as through foliar sprays (0.5 % $ZnSO_4$ and 0.25 % Borax, respectively). The sprays were administered at 30 and 45 DAT. They noticed maximum plant height, number of leaves per plant, fresh bulb weight, leaf girth, total dry matter production and bulb yield following foliar application of $ZnSO_4$ @ 0.5 %.

Tawab *et al*. (2015) investigated the impact of foliar spray of zinc sulphate (0, 0.1, 0.2 and 0.3%) applied to three brinjal varieties (Purple, Shimla and Shamli) at 40 days after transplanting. They concluded that plants of Purple variety sprayed with 0.2 % zinc sulphate led to maximum growth, number of leaves plant^{-1}, number of fruits plant^{-1} and individual fruit weight.

Harris and Mathuma (2015) sprayed different concentrations of boron and zinc (150, 250 and 350 ppm) as well as their combinations on tomato seedlings. Sprays were done thrice at 10 days intervals starting from 40 DAT. They found that Zn @ 250 ppm resulted in maximum plant height, total dry weight, number of fruits plant^{-1} along with fresh weight of fruits plant^{-1}.

Quratul *et al*. (2016) conducted an experiment on broccoli wherein four levels each of zinc and boron (0, 0.25, 0.50 and 1.00 %) were applied through foliar application after one month of transplantation. Among the various treatments, zinc and boron both applied @ 0.5 per cent showed better growth and yield parameters.

Pandav *et al*. (2016) in their investigation on brinjal cv HLB 12 evaluated the effect of foliar application of zinc sulphate, ferrous sulphate and borax applied at various concentrations (0.3, 0.4 and 0.5 %) at 10 days intervals beginning with flowering. They noticed that growth and production features were enhanced by the treatment, $ZnSO_4$ @ 0.4%.

Al-Fadhly (2016) investigated the effect of Zn (60 ppm) and Mn (30 ppm) sprayed separately as well as in combination at vegetative growth stage, tuber initiation stage and tuber bulking stage in potato. They arrived at the conclusion that combined foliar application of the micronutrients (Zn + Mn) during vegetative growth stage increased the mean weight and tuber yield.

Goyal *et al*. (2017) studied the influence of foliar sprays of micronutrients (Zn, Mn, B, and Cu) applied at four concentrations (0.50, 1.00, 0.25 and 1.00 %) alone as well as in combination with each other at 90 days of onion transplanting. They discovered that $ZnSO_4$ @ 0.25 % resulted in the highest net returns along with benefit cost ratio.

Chaudhari *et al*. (2017) tested impact of foliar application of different micronutrients *viz.*, 0.1 % Ammonium molybdate (T_1), 0.2 % Boric acid (T_2), 0.5 % Zinc sulphate (T_3), 0.5 % Copper sulphate (T_4), 0.5 % Ferrous sulphate (T_5), 0.5 % Manganese sulphate (T_6), 1 % General grade-1 (T_7), 0.1 % Ammonium molybdate + 1 % General grade-1 (T_8) all sprayed at 45 and 60 DAT on cauliflower. They observed that treatment T_8 showed the best results with regard to plant growth and yield characteristics.

Sathiyamurthy *et al*. (2017) designed an experiment to determine the response of foliar application of micronutrients on tomato. Boric acid, zinc sulphate, ammonium molybdate, copper sulphate, ferrous sulphate, manganese sulphate each @ 100 ppm and ammonium molybdate @ 50 ppm were used alone as well as in combination. These micronutrients were sprayed thrice starting 40 days after transplanting at 10 days intervals. The results revealed that spraying of mixture of all micronutrients resulted in the highest plant height, number of fruits plant^{-1}, fruit weight, fruit yield and benefit: cost ratio.

Singh *et al*. (2017) conducted an experiment during 2015-2016 comprising two levels of zinc and boron (1.25 and 2.00 g l^{-1}) applied as foliar sprays to cheery tomato, individually as well as in combination along with control at 30, 60, 90, 120 and 150 DAT. They concluded that combined foliar application of zinc and boron each @ 2.0 g l^{-1} was more effective than the individual application of either micronutrient in enhancing plant height, number of leaves plant^{-1}, number of flower clusters plant^{-1}, number of fruit clusters plant^{-1} and fruit yield.

Dixit *et al*. (2018) conducted a trial on tomato cv. Arka Rakshak at Raipur during 2016-2017 involving zinc sulphate, ferrous sulphate and calcium nitrate applied @ 2g l^{-1} along with boron @ 1g l^{-1} sprayed at two stages *i.e.*, 15 and 21 DAT. They reported that mixture of all micronutrients ($ZnSO_4$ @ 0.2 % + $FeSO_4$ @ 0.2 % + Ca $(NO_3)_2$ @ 0.2% + Borax 0.1 %) resulted in maximum plant height, plant girth, minimum days to first flowering, minimum days to first fruiting, minimum days to maturity and maximum values for number of fruits plant^{-1}, fruit length, fruit diameter, fruit weight and yield.

Moklikar *et al*. (2018) investigated the effect of foliar sprays of Zn (0.5%), Bo (0.2%), and Fe (0.3 and 0.5%) alone and in combination with each other sprayed at 45 and 60 days after transplanting in cauliflower. They recorded maximum leaf length, yield plot^{-1} and ascorbic acid in treatment combination involving application of all the micronutrients, *i.e.* $FeSO_4$ 0.5 % + Borax 0.2 % + $ZnSO_4$ 0.5 %.

Taheri *et al*. (2020) investigated the effect of methods and doses of zinc and boron micronutrients on cabbage applied at 45 and 60 days after transplanting alone as well as in combination. Zinc and boron were applied through soil @ 3.0 and 2.0 kg ha^{-1}, respectively whereas foliar sprays of both the micronutrients were given @ 1.0 per cent. They found that foliar application of both the micronutrients tested produced better results for cabbage growth parameters.

Rahman *et al*. (2020) conducted studies on the influence of foliar applications of boron and zinc on okra sprayed thrice alone or in combination at four different levels (0, 0.1, 0.2 and 0.3%), *i.e.* before flowering at 32 DAS, after third picking and at 15 days after the second spray.

They observed that foliar spray before flowering with 0.2 % Borax + 0.2% $ZnSO_4$ increased most of the seed yield attributes and seed yield.

2.3: Effect on other agricultural crops

Nasiri *et al*. (2010) investigated the impact of foliar sprays of Fe and Zn on chamomile (medicinal plant) both applied @ 0.35 % individually as well as in combination with each other at the time of stem elongation, flowering or both the stages. They noticed that flower and essential oil yields were considerably improved when the micronutrients were sprayed at both stages.

Babaeian *et al*. (2011) in their experiment on sunflower tested foliar application of Fe, Zn, and Mn either singly or in combination with each other sprayed at flowering and grain filling stages. They found that application of micronutrients at grain filling stage had the greatest impact on yield and its contributing traits.

Farshid (2012) examined the effect of Zn (0, 8, 16 and 24 kg ha^{-1} as $ZnSO_4$ applied through soil and 0.5 % Zn foliar spray at vegetative stage) and B (0, 3 and 6 kg ha^{-1} B added to the soil and B foliar spray after ear formation @ 0.3 % boric acid) on maize. The results showed that spraying B and Zn enhanced the Fe content of the maize leaves.

Khan *et al*. (2016) conducted experiment on foliar application of zinc sulfate and manganese sulfate (3000 and 4000 ppm) on mustard applied alone and in combination on plants grown under four levels of drought stress *i.e.,* 0, 7, 14 and 21 days. They observed increased plant height, biomass, root length, number of leaves and siliquae $plant^{-1}$ when sprayed with micronutrients.

Fatima *et al*. (2021) looked into the effects of zinc, manganese and iron all applied @ 0.5 % at different stages *i.e*., 25 days after sowing and at flowering stage in black gram. They concluded that foliar application of $ZnSO_4$ @ 0.5 % at 25 DAS increased plant height, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and 1000-grain weight

Chapter – 3

MATERIALS AND METHODS

The present investigation titled, "**Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip**" was carried out at Experimental Farm and Laboratory of the Department of Seed Science and Technology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP during rabi 2021-22. In this chapter, description of the materials used and methods employed during the course of investigation have been discussed in detail.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The Experimental Farm of the Department of Seed Science and Technology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is located in the mid- hill zone of Himachal Pradesh at an altitude of 1250 metres above mean sea level with latitude of 30.5° N and longitude of 77.8° E.

3.1.2 Climate

Climate of the area is generally sub-temperate and semi-humid characterized by cold winters. Generally, December and January months are the coldest while, May and June are the hottest months. Weather data recorded during the cropping season has been depicted in Appendix-I. It was observed that mean monthly maximum and minimum temperatures, average relative humidity and cumulative rainfall recorded during the cropping season were 24.18^0C, 8.3^0C, 56.75 per cent and 395 mm.

3.1.3 Soil

The soil texture of experimental field is loam to clay loam having pH ranging from 6.85-7.05. The soil must be well ploughed and firm.

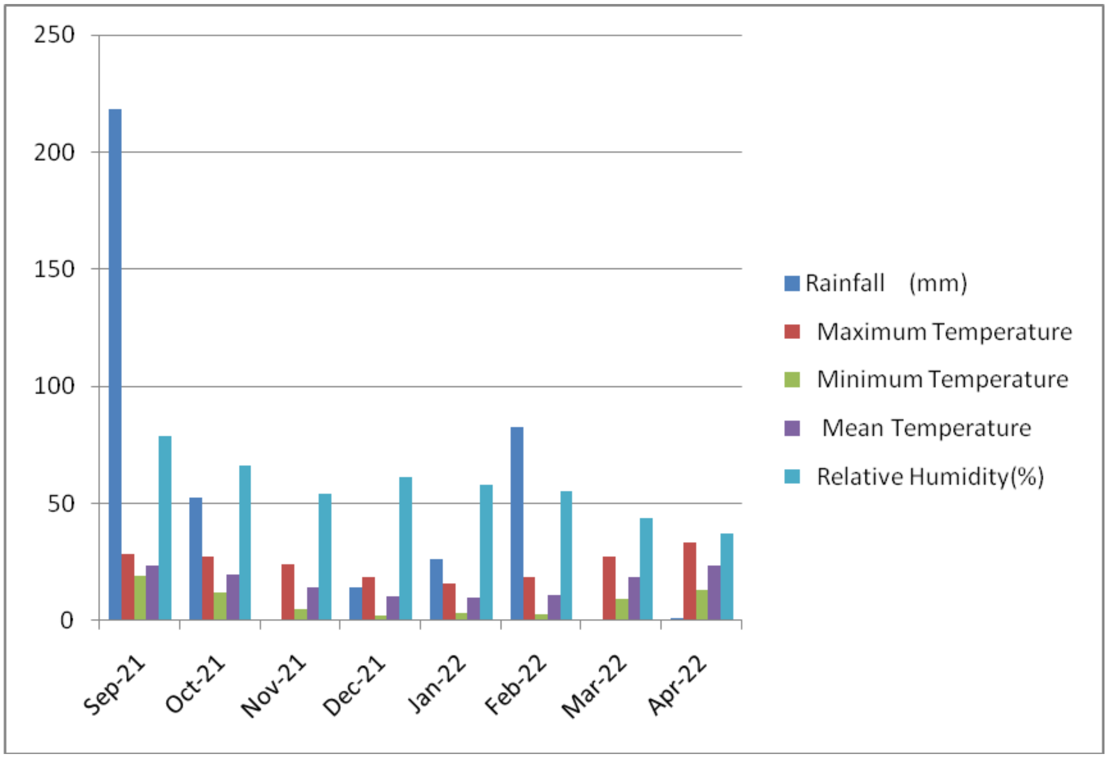

Fig 3.1 Graphical representation of meteorological data during cropping season

3.2 MATERIALS AND METHODOLOGY

3.2.1 Seed source

The seed material was procured from the Department of Seed Science and Technology, Dr YSP University of Horticulture and Forestry, Nauni, Solan (HP).

3.2.2 Cultivar

Turnip cultivar Purple Top White Globe was used under the present investigation. The roots of this variety are nearly round with upper part purple and lower part creamy. Flesh is white, firm and mildly sweet flavoured. The top is small, erect with cut leaves.

3.2.3 Production of roots

Being a root crop, turnip requires loose and friable soil. Therefore, land was ploughed to a fine tilth, ridges and furrows were prepared. Seeds were sown continuously in ridges at a distance of 30 cm (row to row) and later, they were thinned to a distance of 10 cm (plant to plant) during second week of September 2021. A light irrigation was given after sowing and thereafter crop was irrigated once in 6-7 days depending upon weather conditions. FYM, fertilizers and other cultural practices were followed as per the Package of Practices for Vegetable Crops, Directorate of Extension Education, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) to raise a healthy crop of turnip.

3.2.4 Uplifting and selection of roots

When the roots were fully matured, uprooting was done in the month December avoiding any breakage of the roots. After the uprooting of the roots, true to type roots were selected according to the characteristics of the variety under study. Diseased, deformed, forked, split and over matured roots were discarded for the preparation of stecklings.

3.2.5 Preparation of stecklings

The selected roots were used to prepare stecklings by pruning the root tip from the base and leaves up to one third of crown after trimming-off the top.

3.2.6 Planting of stecklings

Stecklings with crown intact were replanted on flat beds at a spacing of 45×30 cm in such a way that upper surface of the shoulder of stecklings was on the level of ground surface. The soil around roots was made firm by pressing with hands. The plots were irrigated immediately after replanting of the stecklings.

3.3 EXPERIMENTAL DETAILS

Crop	**Turnip**
Variety	**Purple Top White Globe**
Treatment combinations	**18**
Replications	**3**
Plot size	**1.8 X 1.8 m**
Spacing	**45 X 30 cm**
Factors	**3**
	1) Zn – 3 Levels (0, 300, 400 ppm)
	2) Mn – 3 Levels (0, 100, 200 ppm)
	3) Stages – 2 (45 DAT, 60 DAT)
Design of experiment	**RBD (Factorial) and CRD**

3.3.1 EXPERIMENTAL LAYOUT

The trial was laid out in Randomized Complete Block Design comprising 18 treatments combinations of different zinc and manganese levels and stages of application with three replications each. The stecklings of turnip were transplanted in the plots having 1.8 X 1.8 m size accommodating 24 plants per plot at a spacing of 45 X 30 cm.

3.3.2 Treatments

Factor A: Levels of zinc

$ZnSO_4$ – 3 levels (0, 300, 400 ppm)

Factor B: Levels of manganese

$MnSO_4$ – 3 levels (0, 100, 200 ppm)

Factor C: Stages of foliar application

S_1 - 45 Days after transplanting
S_2 - 60 Days after transplanting

3.3.3 Treatment Details

Sr. No.	Treatment	Treatment Code	Stages of Application
1.	T_1	$ZnSO_4$ 0 ppm + $MnSO_4$ 0 ppm	45 DAT
2.	T_2	$ZnSO_4$ 0 ppm + $MnSO_4$ 0 ppm	60 DAT
3.	T_3	$ZnSO_4$ 0 ppm + $MnSO_4$ 100 ppm	45 DAT
4.	T_4	$ZnSO_4$ 0 ppm + $MnSO_4$ 100 ppm	60 DAT
5.	T_5	$ZnSO_4$ 0 ppm + $MnSO_4$ 200 ppm	45 DAT
6.	T_6	$ZnSO_4$ 0 ppm + $MnSO_4$ 200 ppm	60 DAT
7.	T_7	$ZnSO_4$ 300 ppm + $MnSO_4$ 0 ppm	45 DAT
8.	T_8	$ZnSO_4$ 300 ppm + $MnSO_4$ 0 ppm	60 DAT
9.	T_9	$ZnSO_4$ 300 ppm + $MnSO_4$ 100 ppm	45 DAT
10.	T_{10}	$ZnSO_4$ 300 ppm + $MnSO_4$ 100 ppm	60 DAT
11.	T_{11}	$ZnSO_4$ 300 ppm + $MnSO_4$ 200 ppm	45 DAT
12.	T_{12}	$ZnSO_4$ 300 ppm + $MnSO_4$ 200 ppm	60 DAT
13.	T_{13}	$ZnSO_4$ 400 ppm + $MnSO_4$ 0 ppm	45 DAT
14.	T_{14}	$ZnSO_4$ 400 ppm + $MnSO_4$ 0 ppm	60 DAT
15.	T_{15}	$ZnSO_4$ 400 ppm + $MnSO_4$ 100 ppm	45 DAT
16.	T_{16}	$ZnSO_4$ 400 ppm + $MnSO_4$ 100 ppm	60 DAT
17.	T_{17}	$ZnSO_4$ 400 ppm + $MnSO_4$ 200 ppm	45 DAT
18.	T_{18}	$ZnSO_4$ 400 ppm + $MnSO_4$ 200 ppm	60 DAT

3.4 OBSERVATIONS RECORDED UNDER FIELD CONDITIONS

The observations were recorded on ten randomly selected plants in each replication for all the growth characters but the yield was worked out on plot basis.

3.4.1 Plant height (cm)

Ten plants were taken randomly from each plot and height was measured from the base to the top of the plant axis and mean height was expressed in centimetres.

3.4.2 Plant spread (cm)

Plant spread was measured from East to West and North to South of the main axis at final harvest and then mean plant spread expressed in centimetres.

3.4.3 Number of siliquae plant^{-1}

Ten random plants were selected and the number of siliquae was counted from the plants in each treatment of the replications and average was worked out.

3.4.4 Siliqua length (cm)

Ten random siliquae were selected treatment-wise for measuring length in each replication and the average was calculated in centimetres.

3.4.5 Number of seeds siliqua^{-1}

Seeds were extracted from ten randomly selected siliquae used for measuring length treatment-wise in each replication and the number of seeds was counted to work out the average.

3.4.6 Days taken to seed maturity

The days were calculated from the time of planting of the stecklings till the harvesting of the seed from the plants in each treatment replication-wise.

3.4.7 Seed yield plant^{-1} (g)

Ten random plants were selected treatment-wise in each replication and the seeds were extracted from all the siliquae of the plants. The seeds were dried and average seed yield was calculated in grams.

3.4.8 Seed yield plot^{-1} (g) and hectare^{-1} (kg)

All the plants in a plot were harvested, seed extracted and weighed to work out seed yield plot^{-1} in grams.

Seed yield hectare^{-1} was calculated as:

$$\text{Seed yield per ha (kg)} = \frac{\text{Seed yield plot}^{-1}\text{ (g) X 8000}}{\text{Plot area (m}^2\text{) X 1000}}$$

3.4.9 1000 seed weight (g)

Random samples of seeds from each treatment were taken and 1000 seeds were counted, weighed and expressed in grams.

3.4.10 Biomass ha^{-1} (kg)

At the harvesting stage, five tagged plants were carefully uprooted at random from a plot and the plants oven dried at a temperature of 70°C for 24 hours after removing the soil adhered to the root zone. The dried plants were cooled under ambient conditions for two hours and weight recorded in grams. Biomass was calculated as:

$$\text{Biomass (kg ha}^{-1}\text{)} = \frac{\text{Dry weight of plant (g) x 8000}}{\text{Area covered by plant x 1000}}$$

3.5 OBSERVATIONS RECORDED UNDER LABORATORY CONDITIONS

3.5.1 Germination (%)

The germination test was carried out as per ISTA procedure using four hundred seeds per treatment (Anonymous, 1985). The seeds were allowed to germinate using paper towel method in a germinator at 25°C and 90 per cent relative humidity. The first and final counts were taken on 5th and 7th day of the test, respectively. Germination percentage was worked out using the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds used}} \text{ X 100}$$

3.5.2 Speed of germination

Number of germinated seeds was counted every day from the first day to n^{th} day and the cumulative index worked out as suggested by Maguire (1962):

$$N=n/1+n/2+..................+n/x$$

Where, ni......nx = number of seeds germinated

3.5.3 Seedling length (cm)

Ten random seedlings were selected at final count and seedling length measured from tip of root to shoot apex with the help of a scale to work out average in centimetres.

3.5.4 Seedling dry weight (mg)

Ten seedlings selected for measuring seedling length were used to work out seedling dry weight. Seedlings were kept in oven at 60°C for 48 hours. After the requisite time, weight was measured and mean expressed in mg.

3.5.5 Seed vigour index-I

Seed vigour index-I was calculated as per the formula given by Abdul-Baki and Anderson (1973):

Seed vigour index-I = Germination (%) X Seedling length (cm)

3.5.6 Seed vigour index-II

Seed vigour index-II was also calculated as per the formula given by Abdul-Baki and Anderson (1973):

Seed vigour index-II = Germination (%) X Seedling dry weight (mg)

3.5.7 Electrical Conductivity (dS m^{-1})

The seed was weighed up to 3 g and the surface sterilization done with $HgCl_2$ (0.1%) for 5-10 minutes. Sterilized samples were washed thoroughly with the water. The washed seeds were dipped in 100 ml of distilled water at room temperature for 24 hours. After the stipulated period, the seeds were removed and the water left was called as the leachate. Then, the electrical conductivity of distilled water was first calculated followed by that of the leachate and finally, the calculation was made on the basis of the formula:

Electrical Conductivity of the sample = EC of leachate - EC of distilled water

3.6 NUTRIENT CONTENT (Zn and Mn in ppm)

Zinc and manganese contents in seed as well as leaves were determined using methodology given by Lindsay and Norvell (1978) and results expressed in ppm.

3.6.1 Seed

Seeds were ground finely and one gram samples from each treatment of every replication were digested in 10 ml di-acid (HNO_3: $HClO_4$ in 4:1 ratio) mixture and final volume made up to 100 ml. Zinc and manganese contents in the digest were determined on atomic absorption spectrophotometer.

3.6.2 Above ground part

One gram oven dried leaf samples from each treatment were digested in 10 ml di-acid (HNO_3: $HClO_4$ in 4:1 ratio) mixture replication-wise and final volume made up to 100 ml. Zinc and manganese contents in the digest were then estimated on atomic absorption spectrophotometer.

3.7 STATISTICAL ANALYSIS:

The statistical analyses for Randomized Complete Block Design (RCBD) and Completely Randomized Design (CRD) were done as per design of the experiments suggested by Gomez and Gomez (1984) using computer software OP Stat.

3.7.1 ANOVA for CRD was as follows:

Source of Variation	**Degree of freedom**	**Sum of Squares**	**Mean sum of squares**	**F cal**
Treatments	(t-1)	S_t	$M_t=S_t/(t-1)$	Mt/Me
Error	t(r-1)	S_e	$M_e=S_e/(t(r-1)$	
Total	(rt-1)	S_T		

Where,

t = Number of treatments
r = Number of replications
S_t =Sum of squares due to treatments

S_r = Sum of squares due to replications

S_e = Sum of squares due to error

M_t = Mean sum of squares due to treatments

M_e = Mean sum of squares due to error

The Critical difference (CD) and Standard Error (SE) for comparing means were calculated as follows:

$$SE\ (d) \pm = \sqrt{2M_e/r}$$

Critical difference ($CD_{0.05}$) = S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) d.f.

Where,

SE (d) ± = Standard error of difference

$CD_{(0.05)}$ = Critical difference at 5 % level of significance

3.7.2 ANOVA for RBD was as follows:

Source of Variation	**Degree of freedom**	**Sum of Squares**	**Mean sum of squares**	**Fcal**
Replications	(r-1)	S_r	$M_r=S_r/(r-1)$	Mr/Me
Treatments	(t-1)	S_t	$M_t=S_t/(t-1)$	Mt/Me
Error	(r-1)(t-1)	S_e	$M_e=S_e/(r-1)(t-1)$	
Total	(rt-1)	S_T		

Where,

r = Number of replications

t = Number of treatments

S_r = Sum of squares due to replications

S_t = Sum of squares due to treatments

S_e = Sum of squares due to error

S_T = Total sum of squares

M_r = Mean sum of squares due to replications

M_t = Mean sum of squares due to treatments

M_e = Mean sum of squares due to error

The replication and treatment mean sum of squares were tested against mean sum of squares due to error by 'F-test' for (r-1), (r-1) (t-1) and (t-1), (r-1) (t-1) degrees of freedom for RBD at 0.05 level of significance.

The calculated F-values were compared with tabulated F-values. When F-test was found significant, critical difference (CD) was calculated to find out the superiority of one treatment over the others.

The standard error and critical differences were calculated as follows:

$CD_{0.05}$ = S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) d.f.

SE (d) ± = $\sqrt{2M_e/r}$

SE (d) ± = Standard error of differences

$CD_{0.05}$= Critical difference at 5% level of significance

Chapter – 4

RESULTS AND DISCUSSION

The present investigation titled, "**Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip** " was carried out at Experimental Farm and Laboratory of the Department of Seed Science and Technology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP during rabi season of 2021-22. The results obtained from the study have been depicted and discussed in this chapter under different headings:

1) EFFECT OF ZINC, MANGANESE AND STAGES OF APPLICATION ON FIELD PARAMETERS

4.1 Plant height (cm)

An inquisition of the data presented in Table 4.1 showed significantly higher plant height (152.05 cm) among different levels of zinc in treatment involving application of $ZnSO_4$ @ 400 ppm. However, the lowest value (144.69 cm) was noticed with water spray ($ZnSO_4$ @ 0 ppm).

A scrutiny of the data presented in Table 4.1 revealed that plant height was significantly influenced by the application of different levels of manganese sulphate in turnip. Maximum plant height (151.92 cm) recorded with foliar application of $MnSO_4$ @ 200 ppm was statistically significant than all other treatments while minimum (145.07 cm) resulted in control ($MnSO_4$ @ 0 ppm).

The data in Table 4.1 pertaining to the effect of stages of application of micronutrients depicted significantly higher plant height in plants receiving these chemicals at 45 days after transplanting (149.37 cm) as compared to 60 days (147.87 cm).

The interaction between zinc and manganese levels was also significant as reflected by combined interaction (Table 4.1). Maximum height (155.19 cm) observed under $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm was statistically significant than the other treatment combinations while minimum (140.15 cm) was recorded under control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). On the other hand, interaction between zinc sulphate and stages of application ($ZnSO_4$ × S) as well as manganese sulphate and stages of application ($MnSO_4$ × S) were found to be non- significant.

Analysis of variance and data presented in Table 4.1 depicted that interaction between $ZnSO_4$ × $MnSO_4$ × S had a significant influence on plant height. Maximum plant height (155.65 cm) attained in plants with combined spray of zinc and manganese $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 days after transplanting which had statistical similarity with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 days after transplanting. However, the lowest value (139.75 cm) was noticed with water spray $ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 60 DAT.

Positive response of zinc in promoting plant height can be explained on the ground that it has a direct role in auxin production, chlorophyll formation, photosynthesis and nitrogen metabolism that ultimately resulted in enhanced cell division and enlargement through increased carbohydrate production. Similar results have also been reported by Santhosha *et al.*, (2022) in carrot.

Similarly, manganese enhanced plant growth because it is essential in plant oxidation and reduction activities such as electron transport in photosynthesis. Moreover, it is also involved in proteins and enzyme formation and its presence is essential for efficient working of Photosystem II (Khan *et al.*, 2016).

Plants treated with different concentrations of $ZnSO_4$ and $MnSO_4$ exhibited a considerable increase in plant height in the present investigation which matched the results of Majid *et al*. (2013). The present results are also in line with the findings of Nadergoli *et al*. (2011) in common bean who opined that both zinc and manganese have a direct bearing on some of the enzyme and involved in systems and hence influence plant height through cell division and cell elongation.

Table 4.1: Effect of foliar application of nutrients, stages of application and their interaction on plant height (cm) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	140.55	145.19	151.97	147.58	149.98	151.29	148.84	153.26	155.65
S_2 (60 DAT)	139.75	143.50	147.16	146.36	148.75	150.71	147.32	152.52	154.72
Interaction $ZnSO_4$ × $MnSO_4$	140.15	144.35	149.57	146.97	149.37	151.00	148.08	152.89	155.19
$MnSO_4$ × Stages of application					**$ZnSO_4$ × Stages of application**				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	145.66	149.48	152.97	149.37	**S_1 (45 DAT)**	145.90	149.62	152.58	149.37
S_2 (60 DAT)	144.48	148.26	150.87	147.87	**S_2 (60 DAT)**	143.47	148.61	151.52	147.87
Mean $MnSO_4$	145.07	148.87	151.92		**Mean $ZnSO_4$**	144.69	149.11	152.05	
$CD_{(0.05)}$	$ZnSO_4$ = 0.57		$MnSO_4$ = 0.57		S = 0.46	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = 0.99					$ZnSO_4$ X $MnSO_4$ X S = 1.40			

4.2 Plant spread (cm)

A careful examination of the data presented in Table 4.2 showed statistically significant differences and maximum plant spread (79.68 cm) was recorded with $ZnSO_4$ @ 400 ppm whereas minimum plant spread (74.03 cm) was observed in water spray ($ZnSO_4$ @0 ppm).

A further examination of the data (Table 4.2) indicated that the application of varied quantities of manganese sulphate also had a significant effect on plant spread. Maximum plant spread (79.53 cm) obtained in treatment $MnSO_4$ @ 200 ppm was statistically significantin comparison to all other treatments while least spread of plant (73.80 cm) was observed in control ($MnSO_4$ @ 0 ppm).

The findings in Table 4.2 depicted that application of micronutrients at different stages of application resulted in a significant increase in plant spread. Plants receiving the chemicals under study at 45 days after transplanting showed maximum plant spread (77.41 cm) as compared to 60 DAT (76.70 cm).

A cursory glance of the data presented in Table 4.2 revealed that interaction between the different levels of zinc sulphate and manganese sulphate had a significant effect on plant spread. Significantly highest plant spread (82.10 cm) was found with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm. However, the lowest value (70.86 cm) was recorded with water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). On the other hand, the interaction between zinc sulphate and stages of application ($ZnSO_4 \times S$) as well as manganese sulphate and stages of application ($MnSO_4 \times S$) were found to be non- significant.

The three-way interaction between $ZnSO_4 \times MnSO_4 \times S$ had a significant influence on plant spread. The combined spray of the micronutrients tested under the present investigation *i.e*. $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 days after transplanting helped to achieve the greatest increase in plant spread (82.17 cm) which was statistically at par with the treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 days. However, water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) produced the lowest figure of plant spread (70.41 cm) at 60 DAT.

Table 4.2: Effect of foliar application of nutrients, stages of application and their interaction on plant spread (cm) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	71.30	75.11	77.14	75.37	78.55	80.70	76.37	81.44	82.17
S_2 (60 DAT)	70.41	73.48	76.75	73.90	77.83	78.39	75.47	80.60	82.04
Interaction $ZnSO_4$ ×$MnSO_4$	70.86	74.30	76.95	74.64	78.19	79.55	75.92	81.02	82.11

$MnSO_4$ × Stages of application					**$ZnSO_4$ × Stages of application**				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	73.86	78.37	80.00	77.41	**S_1 (45 DAT)**	74.52	77.72	79.99	77.41
S_2 (60 DAT)	73.75	77.30	79.06	76.70	**S_2 (60 DAT)**	73.55	77.20	79.37	76.70
Mean $MnSO_4$	73.80	77.84	79.53		**Mean $ZnSO_4$**	74.03	77.46	79.68	
$CD_{(0.05)}$	$ZnSO_4$ = 0.53		$MnSO_4$ = 0.53		S = 0.43	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = 0.92					$ZnSO_4$ X $MnSO_4$ X S = 1.31			

Zinc is helpful for the production and activity of chlorophyll as well as the operation of many enzymes and growth hormones such as auxin. Furthermore, the improvement in growth parameters could be due to effective role of zinc sulphate in controlling various enzyme activities, photosynthetic pigment formation, cell division and the production of certain biochemical growth promoting hormones all of which affect plant growth (Shanwaz *et al*., 2020). Singh *et al*. (2018) also advocated that greater auxin availability to the plant might have enhanced inter-nodal length along with increased apical dominance that could have eventually been beneficial for maximum plant spread. Findings of the present investigation are consistent with previous studies conducted by by Nkoa *et al*. (2002) and Yildirim *et al*. (2007) in broccoli.

Micronutrient manganese is essentially required for plant growth and hence might have been responsible for an increase in plant spread. Moreover, it is essential for natural growth of the plant and completion of its life cycle through involvement in the process of oxidation and reduction as well as transfer of electrons for photosynthetic light reactions(Taiz and Zeiger, 2010).

4.3 Number of siliquae plant^{-1}

An examination of the data in Table 4.3 revealed a statistically significant and maximum number of siliquae plant^{-1} (1198.22) obtained using $ZnSO_4$ @ 400 ppm. The least siliquae number (1049.03) on the other hand was noticed in control ($ZnSO_4$ @ 0 ppm).

A review of the information in Table 4.3 demonstrated that the use of different levels of manganese sulphate had a significant impact on the number of siliquae plant^{-1}. Among different levels of manganese, $MnSO_4$ @ 200 ppm produced the highest siliquae plant^{-1} (1182.14) as compared to all other treatments. Contrary to this, $MnSO_4$ @ 0 ppm resulted in lowest siliquae plant^{-1} (1062.07).

The data (Table 4.3) pertaining to the effect of the foliar application of chemicals under study at different stages *i.e.*, 45 and 60 days after transplanting showed a significant increase in number of siliquae plant^{-1} recorded maximum (1138.96) at 60 days after transplanting as compared to 45 days *i.e.*, 1119.03.

The two-way interaction between Zn and Mn levels, $ZnSO_4$ × S and $MnSO_4$ × S were found to be significant during the investigation as indicated in Table 4.3. The foliar spray of micronutrients resulted in the highest number of siliquae plant^{-1} (1235.29) in treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm. The lowest siliquae plant^{-1} (941.27) was recorded by using water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). Maximum number of siliquae plant^{-1} (1203.22) was obtained with foliar spray of micronutrient $ZnSO_4$ @ 400 ppm at 60 days after transplanting and minimum (1031.32) in control ($ZnSO_4$ @ 0 ppm at 45 DAT). Similarly, the highest number of siliquae plant^{-1} (1184.91) was achieved with micronutrient $MnSO_4$ @ 200 ppm at 60 days after transplanting and the lowest (1044.00) with water spray ($MnSO_4$ @ 0 ppm at 45 DAT).

The interaction between $ZnSO_4$ × $MnSO_4$ × S also had a significant influence on number of siliquae plant^{-1}. The combined spray of both the micronutrients *i.e.* $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT registered the highest number of siliquae plant^{-1} (1238.07) and being statistically at par with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 days after transplanting. However, the lowest number (904.18) was obtained with water spray ($ZnSO_4$ @ 0 ppm + MnSO4 @ 0 ppm at 45 DAT).

Zinc is advantageous in crop productivity because it increases the number of flowers per plant through enhancement in male and female gametogenesis. Not only this, it also stimulates the formation of sporogenous tissue resulting in an increase in the quantity of pollen grains per anther. Furthermore, zinc enhances pollenstigma contact by boosting stigma receptivity and functioning as well as pollenviability all leading to appropriate pollen grain germination and normal growth resulting in an improvement in yield characteristics (Pandey and Gupta, 2012). These findings are in line with those of Nadergoli *et al*. (2011) and Borah and Saikia (2021).

As there was an increase in the plant height and spread with the foliar application of manganese in turnip, increased photosynthetic area might have helped the plants in more accumulation of carbohydrates and their subsequent utilization could have increased the number of siliquae plant^{-1}.

As in the present investigation, there was a synergistic interaction between zinc and manganese for plant height and spread which ultimately might have resulted in a significant increase in carbohydrate assimilation on account of enhanced photosynthetic area ultimately resulting in efficient utilization by the plants and more number of siliquae plant^{-1}. Teixeira *et al*. (2004) also reported increased number of pods plant^{-1} in common bean by foliar application of Zn and Mn.

Table 4.3: Effect of foliar application of nutrients, stages of application and their interaction on number of siliquae plant^{-1} in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	904.18	1072.00	1117.77	1086.39	1123.41	1187.84	1141.42	1205.70	1232.51
S_2 (60 DAT)	978.35	1095.80	1126.08	1116.95	1133.24	1190.59	1145.11	1226.49	1238.07
Interaction $ZnSO_4$ ×$MnSO_4$	941.27	1083.90	1121.92	1101.67	1128.32	1189.22	1143.27	1216.09	1235.29

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	1044.00	1133.70	1179.37	1119.02
S_2 (60 DAT)	1080.13	1151.84	1184.91	1138.96
Mean $MnSO_4$	1062.06	1142.77	1182.14	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	1031.31	1132.54	1193.21	1119.02
S_2 (60 DAT)	1066.74	1146.92	1203.22	1138.96
Mean $ZnSO_4$	1049.03	1139.73	1198.21	

$CD_{(0.05)}$					
	$ZnSO_4$ = 4.91	$MnSO_4$ = 4.91	S = 4.01	$ZnSO_4$ X S = 6.95	$MnSO_4$ X S = 6.95
	$ZnSO_4$ X $MnSO_4$ = 8.51			$ZnSO_4$ X $MnSO_4$ X S = 12.04	

4.4 Siliqua length (cm)

An examination of the data (Table 4.4) indicated that foliar application of zincsulphate in turnip had a significant effect on the siliqua length. Foliar spray of $ZnSO_4$ @ 400 ppm produced the greatest siliqua length (8.01 cm) while control ($ZnSO_4$ @ 0 ppm) resulted in the shortest siliqua length *i.e.*, 7.48 cm.6

An examination of the data presented in Table 4.4 revealed that siliqua length was also influenced significantly by manganese sulphate levels in turnip. Significantly higher siliqua length (8.03 cm) was recorded with $MnSO_4$ @ 200 ppm while the treatment having $MnSO_4$ @ 0 ppm had lowest siliqua length (7.32 cm).

The data (Table 4.4) pertaining to the effect of foliar application of micronutrients under investigation applied at different stages after transplanting of stecklings showed significantly maximum siliqua length at 60 days after transplanting(7.81 cm) as compared to 45 days *i.e.,* 7.65 cm.

Interaction between the levels of zinc and manganese was found to be significant and maximum siliqua length (8.21 cm) noticed in the combined application of micronutrients*i.e.,* $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm was statistically at par with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 2 0 0 ppm However, minimum siliqua length (6.93 cm) was registered with $ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm. On the other hand, interaction between zinc sulphate and stages of application ($ZnSO_4$ × S), manganese sulphate and stages of application ($MnSO_4$ × S) and zinc sulphate, manganese sulphate and stages of application ($ZnSO_4$ × $MnSO_4$ × S) were found to be non- significant.

The increase in siliqua length might be attributed to the fact that zinc is involved in tryptophan synthesis which is a precursor of growth stimulating hormone (auxins) that could have resulted in cell growth and development and ultimately increased siliqua length (Krishna 2000). The results of present investigation areconsistent with those of Pariari *et al*. (2009) in fenugreek.

Similarly, manganese through its involvement in different enzymatic reactionsmight have resulted in an increased siliqua length through expanded photosynthetic area of the plants on account of more plant height and spread ultimately leading to more food reserves for utilization by the plant for different growth processes.

Table 4.4: Effect of foliar application of nutrients, stages of application and their interaction on siliqua length (cm) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	6.85	7.53	7.77	7.25	7.75	7.94	7.67	7.98	8.13
S_2 (60 DAT)	7.01	7.75	7.98	7.33	7.84	8.08	7.81	8.18	8.28
Interaction $ZnSO_4$ × $MnSO_4$	6.93	7.64	7.88	7.29	7.80	8.01	7.74	8.08	8.21

$MnSO_4$ × Stages of application					$ZnSO_4$ × Stages of application				
Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S	Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	7.26	7.75	7.95	7.65	S_1 (45 DAT)	7.38	7.65	7.93	7.65
S_2 (60 DAT)	7.38	7.92	8.11	7.81	S_2 (60 DAT)	7.58	7.75	8.09	7.81
Mean $MnSO_4$	7.32	7.84	8.03		Mean $ZnSO_4$	7.48	7.70	8.01	
$CD_{(0.05)}$	$ZnSO_4$ = 0.08		$MnSO_4$ = 0.08		S = 0.07	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = 0.14					$ZnSO_4$ X $MnSO_4$ X S = NS			

4.5 Number of seeds siliqua^{-1}

An introspection of data (Table 4.5) revealed that foliar application of zincsulphate in turnip had a significant influence on number of seeds siliqua^{-1}. Among thezinc levels, foliar spray of $ZnS0_4$ @ 400 ppm resulted in significantly highest number of seeds siliqua^{-1} (19.67) whereas $ZnS0_4$ @ 0 ppm produced the lowest value (14.45) for this trait.

An inquisition of data (Table 4.5) recorded for number of seeds siliqua^{-1} showed significant impact with varying manganese concentrations. The maximum number of seeds siliqua^{-1} (19.09) observed under foliar spray of $MnSO_4$ @ 200 ppm outperformed all other treatments in terms of statistical significance while the water spray ($MnSO_4$ @ 0 ppm) recorded the least figure (15.13).

The data (Table 4.5) showed that foliar application of zinc and manganese sulphate on turnip crop after 45 and 60 days of transplanting had a significant effect on number of seeds siliqua^{-1}. Significantly highest number of seeds siliqua^{-1} was recorded with foliar spray at 60 days after transplanting *i.e.,* 17.64 as compared to 45 days (17.05).

The combined effect of varying levels of $ZnSO_4$ and $MnSO_4$, $ZnSO_4$ × S and $MnSO_4$ × S were found to be significant during the investigation, as evidenced by the resultspresented in Table 4.5. Maximum number of seeds siliqua^{-1} (22.39) observed under $ZnSO_4$ @400 ppm + $MnSO_4$ @ 200 ppm was statistically significant over all the other treatment combinations while minimum (13.53) was recorded in control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). The highest number of seeds siliqua^{-1} (20.03) was recorded with foliar spray of $ZnSO_4$ @ 400 ppm at 60 days after transplanting as compared to 45 days (14.17). In a similarfashion, significantly highest number of seeds siliqua^{-1} (19.36) was produced with $MnSO_4$ @ 200 ppm at 60 days while lowest(14.69) in control ($MnSO_4$ @ 0 ppm at 45 DAT).

The overall effect of $ZnSO_4$ × $MnSO_4$ × S influenced the number of seeds siliquae^{-1} significantly. The combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT provided the highest seeds siliqua^{-1} (22.63) being statistically superior over other treatment combination. However, the lowest (13.18) was recordedin control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT).

Zinc is essentially involved in glucose metabolism and protein synthesis,which are directly utilized by the seeds. Zinc also enhances nitrogen metabolism and thus, making it available to plants for efficient growth and development, dry matter accumulation and eventually chlorophyll concentration in leaves. Furthermore, foliar zinc is effectively absorbed, assimilated and translocated to growing siliquae resulting in correct siliqua filling and a larger number of seeds siliqua^{-1}. Increased growth is also influenced by the source-sink connection. Moreover, foliar application of zinc promotes plant development via enhanced protein and carbohydrate synthesis which increases thequantity of seeds per siliqua (Al- Isawi., 2010).

An increase observed in the plant height and spread with the foliar applicationof manganese in turnip under the present investigation might be the result of increased photosynthetic rate that could have helped the plants in more accumulation of carbohydrates and their subsequent utilization by the sink *i.e.*, seed ultimately increased the number of well filled seeds.

4.6 Days taken to seed maturity

Data in Table 4.6 elucidated that there were no significant changes in number of days taken to seed maturity by foliar application of zinc sulphate ($ZnSO_4$), manganese sulphate ($MnSO_4$), different stages of application (S) as well as all the two factor and three way interactions.

4.7 Seed yield plant^{-1} (g)

A careful examination of the data (Table 4.7) depicted maximum seed yield plant^{-1} (19.05 g) with foliar spray of $ZnSO_4$ @ 400 ppm which was found to be statistically significant over all other treatments and minimum (13.73 g) obtained with $ZnSO_4$ @ 0 ppm.

A deep insight into the data presented in Table 4.7 revealed that the seed yield plant^{-1} was significantly influenced by the foliar sprays of micronutrient manganese sulphate. The maximum seed yield (18.20 g) recorded in treatment, $MnSO_4$ @ 200 ppm was statistically significant over all other treatments while the foliar spray of $MnSO_4$ @ 0 ppm resulted in lowest seed yield plant^{-1} (14.74 g).

Table 4.5: Effect of foliar application of nutrients, stages of application and their interaction on number of seeds siliqua^{-1} in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	13.18	14.27	15.05	15.74	17.98	19.30	15.15	20.67	22.14
S_2 (60 DAT)	13.88	14.73	15.56	16.38	18.24	19.87	16.44	21.02	22.63
Interaction $ZnSO_4$ ×$MnSO_4$	13.53	14.50	15.31	16.06	18.11	19.59	15.79	20.84	22.39

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	14.68	17.64	18.83	17.05
S_2 (60 DAT)	15.56	17.99	19.35	17.64
Mean $MnSO_4$	15.12	17.81	19.09	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	14.16	17.67	19.32	17.05
S_2 (60 DAT)	14.72	18.16	20.02	17.64
Mean $ZnSO_4$	14.44	17.91	19.67	

$CD_{(0.05)}$	$ZnSO_4$ = 0.09	$MnSO_4$ = 0.09	S = 0.07	$ZnSO_4$ X S = 0.13	$MnSO_4$ X S = 0.13
	$ZnSO_4$ X $MnSO_4$ = 0.16			$ZnSO_4$ X $MnSO_4$ X S = 0.23	

An introspection of the data (Table 4.7) pertaining to the effect of the foliar application of zinc sulphate and manganese sulphate applied at 45 and 60 days after transplanting of stecklings showed significantly maximum seed yield plant^{-1} in plots sprayed at 60 days after transplanting (17.29 g) than micronutrient application at 45 days after transplanting (16.26 g).

The interaction between different levels of $ZnSO_4$ × $MnSO_4$, $ZnSO_4$ × S and $MnSO_4$ × S were also found significant during the study as shown in data presented in Table 4.7. The maximum seed yield plant^{-1} (20.70 g) observed in treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm was statistically superior over all the other treatments while the minimum seed yield plant^{-1} (12.11 g) was recorded in $ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm. The effect of zinc sulphate × Stages of application depicted significantly higher seed yield plant^{-1} (19.45 g) when ZnSO4 @ 400 ppm was sprayed at 60 days after transplanting as opposed to 45 days (13.08 g). Significantly highest seed yield was noticed with $MnSO_4$ @ 200 ppm applied at 60 days (18.80 g) while lowest (14.23) in control *i.e.*, $MnSO_4$ @ 0 ppm at45 DAT.

The overall effect of $ZnSO_4$ × $MnSO_4$ × S influenced the seed yield plant^{-1} significantly. The combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT provided the highest seed yield plant^{-1} (21.19). However, control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT) had lowest seed yield (11.63 g) plant^{-1}.

4.8 Seed yield plot^{-1} (g) and hectare^{-1} (kg)

An examination of the data (Tables 4.8 and 4.9) revealed considerable changes in seed yield plot^{-1} and hectare^{-1} with different zinc sulphate levels. There was a linear increase in seed yield with maximum being recorded at $ZnSO_4$ @ 400 ppm (316.08 g plot^{-1} and 780.45 kg ha^{-1}) and lowest value (261.37 g plot^{-1} and 645.35 kg ha^{-1}) was obtained with $ZnSO_4$ @ 0 ppm.

Table 4.6: Effect of foliar application of nutrients, stages of application and their interaction on days taken to seed maturity in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	124.01	122.96	123.10	124.72	124.08	124.49	123.62	124.90	119.13
S_2 (60 DAT)	122.04	120.86	122.61	124.06	120.48	123.42	121.23	121.20	120.46
Interaction $ZnSO_4$ ×$MnSO_4$	123.03	121.91	122.86	124.39	122.28	123.96	122.43	123.05	119.80

$MnSO_4$ × Stages of application					**$ZnSO_4$ × Stages of application**				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	123.45	122.78	121.88	122.71	**S_1 (45 DAT)**	122.69	122.87	122.55	122.71
S_2 (60 DAT)	123.10	122.04	122.52	122.55	**S_2 (60 DAT)**	122.49	124.21	120.96	122.55
Mean $MnSO_4$	123.28	122.41	122.20		**Mean $ZnSO_4$**	122.59	123.54	121.76	
$CD_{(0.05)}$	$ZnSO_4$ = NS		$MnSO_4$ = NS		S = NS	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = NS					$ZnSO_4$ X $MnSO_4$ X S = NS			

Table 4.7: Effect of foliar application of nutrients, stages of application and their interaction on seed yield plant^{-1} (g) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	11.63	13.28	14.35	15.21	17.68	18.27	15.85	19.88	20.21
S_2 (60 DAT)	12.59	14.62	15.91	16.57	18.25	19.29	16.61	20.54	21.19
Interaction $ZnSO_4$ ×$MnSO_4$	12.11	13.95	15.13	15.89	17.97	18.78	16.23	20.21	20.70

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	14.23	16.94	17.60	16.26
S_2 (60 DAT)	15.25	17.80	18.79	17.28
Mean $MnSO_4$	14.74	17.37	18.20	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	13.08	17.05	18.64	16.26
S_2 (60 DAT)	14.37	18.03	19.44	17.28
Mean $ZnSO_4$	13.72	17.54	19.04	

$CD_{(0.05)}$	$ZnSO_4$ = 0.11	$MnSO_4$ = 0.11	S = 0.09	$ZnSO_4$ X S = 0.15	$MnSO_4$ X S = 0.15
	$ZnSO_4$ X $MnSO_4$ = 0.19			$ZnSO_4$ X $MnSO_4$ X S = 0.27	

A deep insight into the data (Table 4.8 and 4.9) ascertained that there was a considerable variation in seed production plot^{-1} and hectare^{-1} with varying levels of manganese. Significantly highest seed yield (310.87 g plot^{-1} and 767.57 kg ha^{-1}) was noticed with $MnSO_4$ @ 200 ppm and a minimal seed output (269.27 g plot^{-1} and 664.86 kg ha^{-1}) was seen in control ($MnSO_4$ @ 0 ppm).

A cursory examination of the data (Tables 4.8 and 4.9) showed a significant variation in seed production plot^{-1} and hectare^{-1} for different stages of micronutrient application. Significantly higher seed yield was obtained with micronutrient application at 60 days (295.47 g plot^{-1} and 729.54 kg ha^{-1}) than 45 days after transplanting (287.82 g plot^{-1} and 710.66 kg ha^{-1}).

The interaction between $ZnSO_4$ × $MnSO_4$, $ZnSO_4$ × S and $MnSO_4$ × S were found to be significant during the investigation, as evidenced by a scan of the data (Table 4.8 and 4.9). Significantly highest seed yield (338.92 g plot^{-1} and 836.84 kg ha^{-1}) was obtained with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm. On the other hand, control treatment ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) resulted in lowest seed output plot^{-1} and hectare^{-1} (251.38 g plot^{-1} and 620.68 kg ha^{-1}). Among the $ZnSO_4$ × S interactions, significantly higher seed yield (320.48 g plot^{-1} and 791.31 kg ha^{-1}) was recorded with foliar spray of micronutrient $ZnSO_4$ @400 ppm at 60 days after transplanting and minimum (258.11 g plot^{-1} and 637.31 kg ha^{-1})with control $ZnSO_4$ @ 0 ppm at 45 DAT. Significantly highest seed yield (313.84 g plot^{-1} and 774.91 kg ha^{-1}) was achieved with micronutrient $MnSO_4$ @ 200 ppm at 60 days after transplanting and lowest (266.56 g plot^{-1} and 658.16 kg ha^{-1}) with water spray($MnSO_4$ @ 0 ppm at 45 DAT).

The combined effect of $ZnSO_4$ × $MnSO_4$ × S also had a significant influence on seed yield. The combined spray of the two micronutrients helped in achieving highest seed yield (341.29 g plot^{-1} and 842.68 kg ha^{-1}) with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm applied at 60 DAT and lowest (248.29 g plot^{-1} and 613.06 kg ha^{-1}) resulted with water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT).

The highest seed yield was with foliar application of zinc can be attributed to more number of siliqua per plant, siliqua length and number of seeds per siliqua. The improved seed recovery percentage might be attributed to the influence of micronutrients which play an important role in boosting agricultural output. In fact zinc is acknowledged as a critical component in protein synthesis and is also involvedin nitrogen fixation (Deepika and Pitagi, 2015). Hamsaveni *et al*. (2003) also observed similar results in tomato.

Increase in yield with foliar application of manganese could be explained due to increased photosynthetic efficiency and carbohydrate synthesis resulting in more food reserves for conversion into the end product. It also plays a crucial metabolic function in nitrate-reducing enzyme activity and the activation of carbohydrate- metabolizing enzymes (Mousavi *et al*., 2011).

Synergistic effect of the micronutrients ($ZnSO_4$ and $MnSO_4$) under the present investigation might have increased chlorophyll content in the leaves and overall photosynthesis in the plant resultantly providing maximum seed yield (Shanon *et al*., 1992). In their study, Mousavi *et al.* (2007) found that using manganese and zinc applicationenhanced potato yield.

The increase in seed yield (g $plot^{-1}$ and q ha^{-1}) could also be due to increased seed yield $plant^{-1}$ being the resultant of more number of pods per plant, average seed weight per siliqua and 1000 seed weight through foliar application of micronutrients to the crop. These findings have the support of Natesh *et al*. (2005) in chilli and Geetharani *et al*. (2008) in onion.

4.9 Biomass (q ha^{-1})

An examination of the data (Table 4.10) revealed that different concentrationsof zinc had a significant impact on plant biomass. The highest level of zinc *i.e*., $ZnSO_4$ @ 400 ppm produced higher plant biomass (42.69 q ha^{-1}) which was statistically significant over other levels of zinc sulphate minimum (32.84 q ha^{-1}) being observed in control ($ZnSO_4$ @ 0 ppm).

The data (Table 4.10) for plant biomass showed substantial variations between manganese concentrations for this trait. The highest plant biomass (41.21 q ha^{-1}) was recorded with foliar spray of $MnSO_4$ @ 200 ppm being statistically significant compared to all other manganese treatments whereas lowest figure *i.e.*, 35.29 q ha^{-1} was observed in control ($MnSO_4$ @ 0 ppm).

Table 4.8: Effect of foliar application of nutrients, stages of application and their interaction on seed yield plot^{-1} (g) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	248.29	257.45	268.59	268.35	294.09	318.53	283.03	315.47	336.56
S_2 (60 DAT)	254.46	265.00	274.41	271.62	306.45	325.82	289.87	330.29	341.29
Interaction $ZnSO_4$ ×$MnSO_4$	251.38	261.22	271.50	269.98	300.27	322.18	286.45	322.88	338.92

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	266.55	289.00	307.89	287.81
S_2 (60 DAT)	271.98	300.57	313.84	295.46
Mean $MnSO_4$	269.27	294.79	310.86	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	258.11	293.65	311.68	287.81
S_2 (60 DAT)	264.62	301.29	320.48	295.46
Mean $ZnSO_4$	261.36	297.47	316.08	

$CD_{(0.05)}$	$ZnSO_4$ = 0.48	$MnSO_4$ = 0.48	S = 0.39	$ZnSO_4$ X S = 0.68	$MnSO_4$ X S = 0.68
	$ZnSO_4$ X $MnSO_4$ = 0.83			$ZnSO_4$ X $MnSO_4$ X S = 1.18	

Table 4.9: Effect of foliar application of nutrients, stages of application and their interaction on seed yield ha^{-1} (kg) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	613.06	635.67	663.18	662.58	726.14	786.48	698.83	778.94	831.00
S_2 (60 DAT)	628.29	654.31	677.56	670.66	756.66	804.50	715.72	815.51	842.68
Interaction $ZnSO_4$ ×$MnSO_4$	620.68	644.99	670.37	666.62	741.40	795.49	707.28	797.23	836.84

$MnSO_4$ × Stages of application					**$ZnSO_4$ × Stages of application**				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	658.15	713.58	760.22	710.65	**S_1 (45 DAT)**	637.30	725.06	769.59	710.65
S_2 (60 DAT)	671.55	742.16	774.91	729.54	**S_2 (60 DAT)**	653.38	743.93	791.30	729.54
Mean $MnSO_4$	664.85	727.87	767.56		**Mean $ZnSO_4$**	645.34	734.50	780.44	

$CD_{(0.05)}$	$ZnSO_4$ = 1.17	$MnSO_4$ = 1.17	S = 0.96	$ZnSO_4$ X S = 1.66	$MnSO_4$ X S = 1.66
	$ZnSO_4$ X $MnSO_4$ = 2.03			$ZnSO_4$ X $MnSO_4$ X S = 2.88	

The results with regard to the effect of foliar application of different levels of micronutrients on plants at different durations after transplanting were also found to be significant (Table 4.10). Significantly higher plant biomass (38.80 q ha^{-1}) was noticed following micronutrient application at 60 days in comparison to 45 days (37.65 q ha^{-1}) after transplanting.

The combined effect of zinc sulphate and manganese sulphate was discoveredto be significant during the course of investigation as evidenced by the data in Table4.10. The highest plant biomass (45.84 q ha^{-1}) was recorded with $ZnSO_4$ @ 400 ppm+ $MnSO_4$ @ 200ppm. On the other hand, minimal value (30.69 q ha^{-1}) was observedwith $ZnSO_4$ @ 0ppm + $MnSO_4$ @ 0 ppm. However, the combined impact of ($ZnSO_4$× $MnSO_4$ × S), ($ZnSO_4$ × S) and ($MnSO_4$ × S) were found to be non-significant.

Both zinc and manganese increased plant growth parameters that ultimately might have increased the total dry matter production and accumulation in the plants and reflected ashigher biomass. There was a substantial increase in chick pea straw and grain production. This might be attributed to an optimum dose of zinc sulphate which has a considerable effect on grain formation and vegetative development thus increasing biomass (Valenciano *et al.*, 2010).

In the present investigation, there was a significant effect of the interaction between Zn and Mn on plant biomass. This could be due to the role of both zinc and manganese in different biological processes within the plant that might have led to good plant growth and formation of a dense root mass thereby increasing nutrient uptake of the major plant nutrientssuch as nitrogen, phosphorus and potassium from the soil and resultantly increased the amount of these nutrients in the vegetative parts directly reflected in the form of plant biomass.

4.10 1000 seed weight (g)

An introspection of the data (Table 4.11) revealed a statistically significant effect of different zinc levels recording maximum seed weight (1.76 g) with foliar application of $ZnSO_4$ @ 400 ppm, however, lowest value (1.66 g) was observed with water spray ($ZnSO_4$ @ 0 ppm).

Table 4.10: Effect of foliar application of nutrients, stages of application and their interaction on plant biomass(q ha^{-1}) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	30.33	31.26	35.58	36.48	38.18	40.76	37.47	43.01	45.81
S_2 (60 DAT)	31.05	32.63	36.18	37.35	39.16	43.04	39.08	44.87	45.87
Interaction $ZnSO_4 \times MnSO_4$	30.69	31.95	35.88	36.92	38.67	41.90	38.28	43.94	45.84

$MnSO_4$ × Stages of application					$ZnSO_4$ × Stages of application				
Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S	Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	34.76	37.49	40.72	37.65	S_1 (45 DAT)	32.39	38.47	42.10	37.65
S_2 (60 DAT)	35.83	38.89	41.70	38.80	S_2 (60 DAT)	33.29	39.85	43.27	38.80
Mean $MnSO_4$	35.29	38.19	41.21		Mean $ZnSO_4$	32.84	39.16	42.69	
$CD_{(0.05)}$	$ZnSO_4$ = 1.06		$MnSO_4$ = 1.06		S = 0.86	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = 1.84					$ZnSO_4$ X $MnSO_4$ X S = NS			

An examination of the data presented in Table 4.11 demonstrated that the administration of varied quantities of manganese to turnip considerably impacted 1000 seed weight. Statistically significant and higher 1000 seed weight (1.75 g) was registered in the treatment involving foliar spray of $MnSO_4$ @ 200 ppm while control ($MnSO_4$ @ 0 ppm) produced lowest figure (1.67 g) for this trait.

The data (Table 4.11) on the effect of different stages of micronutrient applications showed significant increase in 1000 seed weight when sprayed 60 days after transplanting (1.73 g) as compared to 45 DAT (1.71 g).

The interaction between zinc sulphate and manganese sulphate was also found to be significant during the experiment as indicated by the data in Table 4.11. Significantly higher 1000 seed weight (1.81 g) was obtained with combined application of the micronutrients *i.e.*, $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm whereas lowest weight (1.62 g) with $ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm. The cumulative effects of $ZnSO_4$ × S, $MnSO_4$ × S and $ZnSO_4$ × $MnSO_4$ × S were found to be non-significant.

The weight of seed is an essential quality indicator. Hence, higher the test weight better will be the germination potential and vigour of the seed lot and more uniform plant stand resulting from such seed will ultimately ensure higher yield of quality produce. Usman *et al*. (2014) also reported increase in 1000 seed weight which might be due to optimum spray of zinc sulphate dose positively affecting the cell division, sugar and starch formation which could have led to an increase in seed weight.

Increase in seed weight due to manganese may be explained on the ground that this micronutrient plays an important role in activating various enzymes responsible for glucose metabolism and phosphorylation. Nadergoli *et al*. (2011) havealso reported similar results.

Table 4.11: Effect of foliar application of nutrients, stages of application and their interaction on 1000 seed weight in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	1.62	1.65	1.69	1.68	1.72	1.74	1.69	1.76	1.80
S_2 (60 DAT)	1.63	1.66	1.70	1.69	1.75	1.76	1.71	1.81	1.82
Interaction $ZnSO_4$ × $MnSO_4$	1.63	1.66	1.70	1.69	1.74	1.75	1.70	1.79	1.81

$MnSO_4$ × Stages of application					$ZnSO_4$ × Stages of application				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	1.66	1.71	1.74	1.71	**S_1 (45 DAT)**	1.65	1.71	1.75	1.71
S_2 (60 DAT)	1.68	1.74	1.76	1.73	**S_2 (60 DAT)**	1.66	1.73	1.78	1.73
Mean $MnSO_4$	1.67	1.72	1.75		**Mean $ZnSO_4$**	1.66	1.72	1.76	
$CD_{(0.05)}$	$ZnSO_4$ = 0.01		$MnSO_4$ = 0.01		S = 0.01	$ZnSO_4$ X S = NS		$MnSO_4$ X S = NS	
	$ZnSO_4$ X $MnSO_4$ = 0.02					$ZnSO_4$ X $MnSO_4$ X S = NS			

2) EFFECT OF ZINC, MANGANESE AND STAGES OF APPLICATION ON SEED QUALITY PARAMETERS

4.11 Germination (%)

A closer look of the data (Table 4.12) indicated significant differences in germination of harvested seeds for varied zinc sulphate levels. There was a linear rise in germination percentage of harvested seeds being highest (92.46 %) with $ZnSO_4$ @ 400 ppm. Contrary to this, lowest value (88.65 %) was attained in control ($ZnSO_4$ @0 ppm).

A cursory examination of the data (Table 4.12) revealed that there was a significant variation in germination of harvested seeds for different levels of manganese sulphate. Significantly higher germination percentage (92.20 %) was found in treatment $MnSO_4$ @ 200 ppm while with minimal figure (88.89 %) in control ($MnSO_4$ @ 0 ppm).

A brief assessment of the data (Table 4.12) indicated that there was a significant variation in germination percentage between stages of micronutrient applications. It was found that germination of harvested seeds with micronutrient spray at 60 days was significantly higher (91.19 %) than the value observed 45 days after transplanting (90.07 %).

A scan of the data (Table 4.12) showed that the interaction between $ZnSO_4$ × $MnSO_4$, $ZnSO_4$ × S and $MnSO_4$ × S was found to be significant during the experiment. Interaction between zinc and manganese resulted in significantly highest germination (94.51 %) with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm however, water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) recorded lowest germination (86.53 %). Among $ZnSO_4$ × S interactions, highest germination percentage of harvested seed (92.97 %) was attained with foliar application of micronutrient $ZnSO_4$ @ 400 ppm at 60 DAT while lowest (88.41 %) in the control ($ZnSO_4$ @ 0 ppm at 45 DAT). Similar to this, out of different $MnSO_4$ × S interactions, $MnSO_4$ @ 200 ppm at 60 days after transplanting produced significantly highest germination (92.76 %) whereas water spray *i.e.*, $MnSO_4$ @ 0 ppm at 45 DAT resulted in lowest figure (88.37 %).

The three way interaction of $ZnSO_4$ × $MnSO_4$ × S also had a significant effect on seed germination percentage. The combined foliar spray of micronutrients $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT recorded highest germination (94.86 %). On the other hand water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT) resulted in lowest (86.36 %) for this parameter.

Seed germination reflects physiological status of a seed lot giving an idea about the potential of seeds to establish and give a good plant stand under varied fieldconditions. So, it is obvious from the present investigation that physiologically sound, bold and better seeds with higher dry matter accumulation might have resulted in higher and uniform germination. Hence, an increase in germination has been noticed. The results have confirmation with the studies of Yoganand (2001) in bell pepper andSharma (2019) in radish.

4.12 Speed of germination

A careful examination of the data Table 4.13 showed that different zinc sulphate levels resulted in substantial changes in speed of germination of harvested seed. Speed of germination increased linearly (11.62) up to the highest level of zinc *i.e.*, $ZnSO_4$ @ 400 ppm. However, water spray ($ZnSO_4$ @ 0 ppm) had lowest speed ofgermination (10.50).

A detailed enquiry of the data (Table 4.13) demonstrated that varied manganese sulphate levels resulted in significant differences in the speed of germination of harvested seed. Here also, speed of germination rose linearly being highest (11.54) with $MnSO_4$ @ 200 ppm, On the other hand, control ($MnSO_4$ @ 0 ppm) had lowest speed of germination (10.48).

The results with regard to the effect of foliar application of chemicals on plants at 45 and 60 days after transplanting revealed that significantly higher speed ofgermination (11.26) was noticed in seed harvested from the plants receiving micronutrient spray at 60 days as compared to 45 days (10.85) after transplanting.

A cursory review of the data (Table 4.13) indicated that the correlation among zinc sulphate and manganese sulphate concentrations was found to have significant effect on this trait. Significantly best speed of germination (12.38) was obtained with spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm. However, water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) had least speed of germination (10.23). Interaction between zinc and stages of application resulted in significantly faster germination rate (11.84) with $ZnSO_4$ @ 400 ppm sprayed at 60 days compared to 45 days (10.38) after transplanting. Likewise, interaction between manganese and stages of application produced significantly greater speed of germination (11.75) with $MnSO_4$ @ 200 ppm applied at 60 DAT. However, least value (10.32) was obtained in control ($MnSO_4$ @ 0 ppm at 45 DAT).

Germination (%) in T_1- Water spray at 45 DAT

Germination (%) in T_{18}- $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT

Plate 2. Germination (%)

Table 4.12: Effect of foliar application of nutrients, stages of application and their interaction on germination (%) in turnip

Stages of application	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	86.36 (9.34)	88.64 (9.46)	90.22 (9.55)	89.13 (9.49)	89.93 (9.53)	90.53 (9.56)	89.62 (9.51)	92.08 (9.64)	94.16 (9.75)
S_2 (60 DAT)	86.70 (9.36)	88.96 (9.48)	91.04 (9.59)	91.28 (9.60)	91.40 (9.61)	92.39 (9.66)	90.27 (9.55)	93.77 (9.73)	94.86 (9.79)
Interaction $ZnSO_4$ ×$MnSO_4$	86.53 (9.35)	88.80 (9.47)	90.63 (9.57)	90.20 (9.55)	90.66 (9.57)	91.46 (9.61)	89.95 (9.53)	92.93 (9.69)	94.51 (9.77)

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	88.36 (9.45)	90.21 (9.55)	91.63 (9.62)	90.07 (9.54)
S_2 (60 DAT)	89.41 (9.50)	91.37 (9.61)	92.76 (9.68)	91.18 (9.60)
Mean $MnSO_4$	88.89 (9.48)	90.79 (9.58)	92.20 (9.65)	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	88.40 (9.45)	89.86 (9.53)	91.95 (9.64)	90.07 (9.54)
S_2 (60 DAT)	88.90 (9.48)	91.68 (9.62)	92.96 (9.69)	91.18 (9.60)
Mean $ZnSO_4$	88.65 (9.46)	90.77 (9.58)	92.46 (9.66)	

$CD_{(0.05)}$					
	$ZnSO_4$ = 0.004	$MnSO_4$ = 0.004	S = 0.004	$ZnSO_4$ X S = 0.006	$MnSO_4$ X S = 0.006
	$ZnSO_4$ X $MnSO_4$ = 0.007			$ZnSO_4$ X $MnSO_4$ X S = 0.011	

The three-way interaction, $ZnSO_4$ × $MnSO_4$ × S also influenced the speed of germination significantly. The combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 days after transplanting resulted in significantly higher rate of germination (12.58). On the contrary, water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT) had lowest value (10.19) for this trait.

The faster rate of germination under the present investigation could be attributed to more boldness and higher quality of seeds produced following application of both the micronutrients due to their involvement in a variety of catalytic processes. Not only this, synergistic effect of the micronutrients under study is known to positively influence the availability of nutrients and growth stimulating elements to the plants thereby increasing the buildup of dry matter content in the seeds.

4.13 Seedling length (cm)

A comprehensive study of the data (Table 4.14) revealed that $ZnSO_4$ levels resulted in significant differences in the seedling length. Foliar spray of $ZnSO_4$ @ 400 ppm resulted in significantly higher seedling length (16.89 cm) while minimum figure (12.74 cm) was observed in control ($ZnSO_4$ @ 0 ppm).

A thorough examination of the data (Table 4.14) showed that different $MnSO_4$ levels also caused significant changes in seedling length. Significantly higher seedling length (16.67 cm) was recorded using $MnSO_4$ @ 200 ppm whereas water spray ($MnSO_4$ @ 0 ppm) had minimum value (13.94 cm) for the parameter.

An introspection of the data (Table 4.14) indicated a significant variation in seedling length with stages of micronutrient application. Significantly higher seedlinglength of (15.58 cm) observed at 60 days after transplanting which showed a considerable decline having a minimum value (14.85 cm) in control ($MnSO_4$ @ 0 ppm 45 DAT).

Speed of germination in T_1- Water spray at 45 DAT

Speed of germination in T_{18}- $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT

Plate 4. Speed of germination

Table 4.13: Effect of foliar application of nutrients, stages of application and their interaction on speed of germination in turnip

Stages of application	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	10.19	10.46	10.48	10.08	10.91	11.30	10.70	11.35	12.17
S_2 (60 DAT)	10.27	10.67	10.96	10.76	11.46	11.72	10.89	12.06	12.58
Interaction $ZnSO_4$ ×$MnSO_4$	10.23	10.56	10.72	10.42	11.18	11.51	10.79	11.70	12.38

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	10.32	10.90	11.31	10.84
S_2 (60 DAT)	10.63	11.39	11.75	11.26
Mean $MnSO_4$	10.48	11.14	11.53	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	10.37	10.76	11.40	10.84
S_2 (60 DAT)	10.63	11.31	11.84	11.26
Mean $ZnSO_4$	10.50	11.03	11.62	

$CD_{(0.05)}$	$ZnSO_4$ = 0.09	$MnSO_4$ = 0.09	S = 0.08	$ZnSO_4$ X S = 0.13	$MnSO_4$ X S = 0.13
	$ZnSO_4$ X $MnSO_4$ = 0.16			$ZnSO_4$ X $MnSO_4$ X S = 0.23	

Table 4.14: Effect of foliar application of nutrients, stages of application and their interaction on seedling length(cm) in turnip

Stages of application	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	11.45	12.20	13.66	14.68	15.35	16.90	14.59	16.21	18.58
S_2 (60 DAT)	11.85	13.07	14.20	15.63	15.74	17.77	15.44	17.60	18.90
Interaction $ZnSO_4$ × $MnSO_4$	11.65	12.64	13.93	15.16	15.55	17.34	15.02	16.91	18.74

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	13.57	14.59	16.38	14.85
S_2 (60 DAT)	14.31	15.47	16.96	15.58
Mean $MnSO_4$	13.94	15.03	16.67	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	12.44	15.65	16.46	14.85
S_2 (60 DAT)	13.04	16.38	17.31	15.58
Mean $ZnSO_4$	12.74	16.01	16.89	

$CD_{(0.05)}$					
	$ZnSO_4$ = 0.10	$MnSO_4$ = 0.10	S = 0.08	$ZnSO_4$ X S = 0.15	$MnSO_4$ X S = 0.15
	$ZnSO_4$ X $MnSO_4$ = 0.18			$ZnSO_4$ X $MnSO_4$ X S = 0.26	

Seedling length in T_1- Water spray at 45 DAT

Seedling length in T_{18}- $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT

Plate 3. Seedling length

A preliminary examination of the data (Table 4.14) demonstrated that the association between $ZnSO_4$ and $MnSO_4$ concentrations had significant effect during the present investigation. The spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm produced the longest seedling length (18.74 cm). However, the water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) had the shortest seedling length (11.65 cm). The impact of $ZnSO_4$ × Stages of application showed a significantly higher seedling length (17.31 cm) with $ZnSO_4$ @ 400 ppm applied 60 DAT in contrast to 45 DAT (12.44 cm). Similarly, Significantly $MnSO_4$ × Stages of application interaction resulted in the longest seedling length (16.96 cm) with $MnSO_4$ @ 200 ppm applied at 60 DAT as compared to control ($MnSO_4$ @ 0 ppm DAT) which resulted in shortest (13.57 cm) seedlings.

The three-way interaction, $ZnSO_4$ × $MnSO_4$ × S had a significant impact on seedling length. At 60 DAT, the combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm contributed in significantly longer seedlings (18.90 cm) whereas control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT) had the lowest value (11.45 cm).

The longer seedlings might be linked to the strong and healthy seeds having more stored food reserves. The role of both zinc and manganese is well established in enhancing the activity of auxins (Cakmak 2008) which result in rapid cell divison and cell elongation ultimately producing healthier and longer seedlings. The results are in agreement with the findings of Kiran (2006) in brinjal.

4.14 Seedling dry weight (mg)

The data **(**Table 4.15) indicated that different zinc sulphate levels had a significant effect on seedling dry weight. Significantly higher seedling dry weight (10.20 mg) was obtained with foliar spray of $ZnSO_4$ @ 400 ppm. In contrast, minimum weight (8.75 mg) was recorded in control ($ZnSO_4$ @ 0 ppm).

Table 4.15 showed that varying manganese sulphate levels also had a significant influence on seedling dry weight. Foliar spray of $MnSO_4$ @ 200 ppm resulted in signicifantly highest seedling dry weight (10.40 mg) and lowest value (8.42 mg) noticedin control ($MnSO_4$ @ 0 ppm).

An examination of the data (Table 4.15) revealed a significant variation in seedling dry weight with stages of micronutrient applications. Significantly higher seedling dry weight (9.65 mg) was recorded when micronutrients were sprayed at 60 days than at 45 DAT (9.26 mg) after transplanting.

A cursory examination of the data presented in Table 4.15 indicated that $ZnSO_4$ × $MnSO_4$ interaction had significant effect during the present investigation. Foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm generated the greatest seedling dry weight (11.52 mg). Contrary to this, lowest seedling dry weight (7.52 mg) was observed in control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). All other two and three factor interactions were found to be non-significant.

The increased seedling dry weight in treatment, $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm may be attributed to the fact that higher dose of zinc coupled with manganese might have produced bolder and higher quality seeds, resulting in the production of larger seedlings with higher fresh and dry weight. The rapid seedling development also corresponded with larger seedling dry matter content, leading in an increase in seedling dry weight.

4.15 Seed vigour index-I

It is apparent from the data (Table 4.16) that seed vigour index-I was significantly affected by various zinc levels. Among different zinc levels, significantly higher SVI-I (1564.45) was observed in $ZnSO_4$ @ 400 ppm up to which there was a linear increase in the values of this parameter and after that there was decline in SVI-I with minimum (1131.02) being recorded in water spray ($ZnSO_4$ @ 0 ppm).

The data (Table 4.16) showed that manganese levels also had a significant impact on seed vigour index-I. Among various manganese levels, significantly maximum SVI-I (1539.94) was detected in treatment $MnSO_4$ @ 200 ppm and lowest (1242.15) observed when plants were sprayed with water ($MnSO_4$ @ 0 ppm).

Between stages of application, there was a significant variation in seed vigour index-I with maximum SVI-I (1425.26) being obtained following sprays at 60 days after transplanting and then gradually it reduced to a minimum (1341.35) at 45 DAT.

Table 4.15: Effect of foliar application of nutrients, stages of application and their interaction on seedling dry weight (mg) in turnip

Stages of application	$ZnSO_4$ 0 ppm: $MnSO_4$ 0 ppm	$ZnSO_4$ 0 ppm: $MnSO_4$ 100 ppm	$ZnSO_4$ 0 ppm: $MnSO_4$ 200 ppm	$ZnSO_4$ 300 ppm: $MnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm: $MnSO_4$ 100 ppm	$ZnSO_4$ 300 ppm: $MnSO_4$ 200 ppm	$ZnSO_4$ 400 ppm: $MnSO_4$ 0 ppm	$ZnSO_4$ 400 ppm: $MnSO_4$ 100 ppm	$ZnSO_4$ 400 ppm: $MnSO_4$ 200 ppm
S_1 (45 DAT)	7.34	8.65	9.66	8.66	9.37	9.84	8.40	9.93	11.46
S_2 (60 DAT)	7.70	9.36	9.80	8.98	9.59	10.03	9.45	10.39	11.57
Interaction $ZnSO_4$ × $MnSO_4$	7.52	9.01	9.73	8.82	9.48	9.94	8.93	10.16	11.52

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	8.14	9.32	10.32	9.26
S_2 (60 DAT)	8.71	9.78	10.47	9.65
Mean $MnSO_4$	8.42	9.55	10.40	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	8.55	9.29	9.93	9.26
S_2 (60 DAT)	8.96	9.53	10.47	9.65
Mean $ZnSO_4$	8.75	9.41	10.20	

$CD_{(0.05)}$					
$ZnSO_4$ = 0.35	$MnSO_4$ = 0.35	S = 0.29	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
$ZnSO_4$ X $MnSO_4$ = 0.61			$ZnSO_4$ X $MnSO_4$ X S = NS	

Table 4.16: Effect of foliar application of nutrients, stages of application and their interaction on seed vigour index-I in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	988.79	1081.70	1232.15	1308.38	1380.84	1530.35	1307.55	1492.67	1749.73
S_2 (60 DAT)	1027.68	1162.67	1293.12	1427.01	1438.30	1641.78	1393.47	1650.76	1792.54
Interaction $ZnSO_4$ ×$MnSO_4$	1008.24	1122.19	1262.64	1367.70	1409.57	1586.07	1350.51	1571.72	1771.14

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	1201.57	1318.41	1504.08	1341.35
S_2 (60 DAT)	1282.72	1417.24	1575.81	1425.26
Mean $MnSO_4$	1242.15	1367.82	1539.94	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	1100.88	1406.53	1516.65	1341.35
S_2 (60 DAT)	1161.16	1502.36	1612.25	1425.26
Mean $ZnSO_4$	1131.02	1454.45	1564.45	

$CD_{(0.05)}$	$ZnSO_4$ = 9.81	$MnSO_4$ = 9.81	S = 8.01	$ZnSO_4$ X S = 13.88	$MnSO_4$ X S = 13.88
	$ZnSO_4$ X $MnSO_4$ = 17.00			$ZnSO_4$ X $MnSO_4$ X S = 24.04	

An insight into the data (Table 4.16) indicated that among different treatment combinations of zinc and manganese, significantly highest seed vigour index-I (1771.13) registered with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm was statistically superior to the remaining treatment combinations. On the other hand, minimum SVI-I (1008.24) was obtained in control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm). Out of the $ZnSO_4$ × S interactions, foliar spray of trace mineral $ZnSO_4$ @ 400 ppm at 60 DAT produced significantly higher SVI-I (1612.25) than spray of $ZnSO_4$ @ 0 ppm at 45 DAT (control). As regards the effect of $MnSO_4$ × S interactions, significantly highest SVI-I (1575.81) was attained with micronutrient $MnSO_4$ @ 200 ppm at 60 DAT and the lowest (1201.57) in water spray (MnSO4 @ 0 ppm at 45 DAT).

The overall impact of $ZnSO_4$ × $MnSO_4$ × S also had a significant influence on seed vigour index-I. The combined micronutrient spray $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm applied at 60 DAT resulted in the highest SVI-I (1792.54) being statistically significant than rest of the combinations, however, lowest figure (988.79) resulted in control (ZnSO4 @ 0 ppm + MnSO4 @ 0 ppm 45 DAT).

The germination test alone may not be sufficient to provide all of the information on seed performance under field circumstances where the seeds are subjected to various environmental stresses. Thus, assessing the seed vigour index-I of the seed lot is an important property for determining seed quality since it gives truegerminability and potential of seeds to perform under field circumstances. As a result, greater seed vigour index-I values may be attributed to the seeds capacity to record higher germination percentages and grow longer seedlings with better quality upon germination.

4.16 Seed vigour index-II

An introspection of the data (Table 4.17) indicated significant influence of zinc levels on seed vigour index-II. A continuous increase in the SVI-II was observed withadvancing levels of this micronutrient terminating at highest value (942.03) in treatment, $ZnSO_4$ @ 400 ppm being significantly different from the remaining levels. Minimum value (784.32) for the trait was however recorded in control ($ZnSO_4$ @ 0 ppm).

An assessment of the data (Table 4.17) revealed that manganese levels had a significant impact on seed vigour index-II. A continuous rise in SVI-II was seen under varying levels of manganese resulting in significantly highest figure (943.78) with $MnSO_4$ @ 200 ppm whereas minimum SVI-II (785.78) observed in control $MnSO_4$ @ 0 ppm.

There was a significant fluctuation in seed vigour index-II with stages ofmicronutrient application. (Table 4.17) Significantly higher SVI-II (891.25) was obtained in harvested seed that resulted from plants receiving micronutrient sprays at 60 days after transplanting than those plants which were sprayed at 45 DAT (837.01).

The interaction between various levels of $ZnSO_4$ × $MnSO_4$ concentrations also exerted a significant impact on the SVI-II (Table 4.17). A careful examination of the data showed that a combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm produced seedlings with highest SVI-II (1087.07) which was statistically superior over rest of the treatment combinations tried under the present investigation. Control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) on the other hand had the lowest SVI-II (682.75). All other interactions $MnSO_4$ × S, $ZnSO_4$ × S and $ZnSO_4$ × $MnSO_4$ × S were found to be non-significant.

Seed vigour index-II is a derived parameter and hence the highest figure achieved with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm might be related to a better percentage of seed germination and a higher seedling dry weight.

4.17 Electrical conductivity (dS m^{-1})

An examination of the data (Table 4.18) clearly indicated significant changes in electrical conductivity of the seed with varying levels of zinc sulphate. Seeds harvested from the plants that were sprayed with $ZnSO_4$ @ 400 ppm had minimum seed electrical conductivity of (0.028 dS m^{-1}) being significantly lower (0.034 dS m^{-1})than that recorded in treatment, $ZnSO_4$ @ 0 ppm (Control).

A critical review of the data (Table 4.18) exhibited a considerable difference in electrical conductivity for different levels of manganese sulphate. Following a similar trend as for zinc, higher level of manganese *i.e.*, $MnSO_4$ @ 200 ppm recorded minimum conductivity (0.030 dS m^{-1}) being statistically superior over treatment$MnSO_4$ @ 0 ppm *i.e.,* (0.033 dS m^{-1}).

A quick analysis of the data (Table 4.18) indicated that there was a significantvariation in electrical conductivity between the stages of micronutrient application. Significantly lower electrical conductivity of seed (0.031 dS m^{-1}) was observed at 60 days after transplanting than that at 45 DAT (0.031 dS m^{-1}).

Table 4.17: Effect of foliar application of nutrients, stages of application and their interaction on seed vigour index-II in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	635.62	769.33	848.22	861.29	797.89	868.98	752.16	914.07	1085.53
S_2 (60 DAT)	729.88	849.39	873.47	899.16	871.08	897.87	836.57	975.23	1088.61
Interaction $ZnSO_4$ ×$MnSO_4$	682.75	809.36	860.85	880.23	834.49	883.43	794.37	944.65	1087.07

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	749.69	827.10	934.24	837.01
S_2 (60 DAT)	821.87	898.57	953.32	891.25
Mean $MnSO_4$	785.78	862.83	943.78	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	751.06	842.72	917.25	837.01
S_2 (60 DAT)	817.58	889.37	966.80	891.25
Mean $ZnSO_4$	784.32	866.04	942.03	

$CD_{(0.05)}$	$ZnSO_4$ = 37.85	$MnSO_4$ = 37.85	S = 30.90	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
	$ZnSO_4$ X $MnSO_4$ = 65.56			$ZnSO_4$ X $MnSO_4$ X S = NS	

Table 4.18: Effect of foliar application of nutrients, stages of application and their interaction on electrical conductivity (dS m^{-1}) in turnip

	ZnSO$_4$ 0 ppm			ZnSO$_4$ 300 ppm			ZnSO$_4$ 400 ppm		
Stages of application	**MnSO$_4$ 0 ppm**	**MnSO$_4$ 100 ppm**	**MnSO$_4$ 200 ppm**	**MnSO$_4$ 0 ppm**	**MnSO$_4$ 100 ppm**	**MnSO$_4$ 200 ppm**	**MnSO$_4$ 0 ppm**	**MnSO$_4$ 100 ppm**	**MnSO$_4$ 200 ppm**
S$_1$ (45 DAT)	0.036	0.034	0.033	0.033	0.032	0.029	0.032	0.028	0.026
S$_2$ (60 DAT)	0.035	0.033	0.034	0.030	0.032	0.030	0.029	0.027	0.025
Interaction ZnSO$_4$ ×MnSO$_4$	0.036	0.034	0.034	0.032	0.032	0.030	0.031	0.028	0.026

MnSO$_4$ × Stages of application					**ZnSO$_4$ × Stages of application**				
Stages of application	**MnSO$_4$ 0 ppm**	**MnSO$_4$ 100 ppm**	**MnSO$_4$ 200 ppm**	**Mean S**	**Stages of application**	**ZnSO$_4$ 0 ppm**	**ZnSO$_4$ 300 ppm**	**ZnSO$_4$ 400 ppm**	**Mean S**
S$_1$ (45 DAT)	0.033	0.031	0.029	0.031	**S$_1$ (45 DAT)**	0.034	0.030	0.029	0.031
S$_2$ (60 DAT)	0.032	0.031	0.030	0.031	**S$_2$ (60 DAT)**	0.034	0.032	0.027	0.031
Mean MnSO$_4$	0.033	0.031	0.030		**Mean ZnSO$_4$**	0.034	0.031	0.028	
CD$_{(0.05)}$	ZnSO$_4$ = 0.001		MnSO$_4$ = 0.001		S = 0.001	ZnSO$_4$ X S = NS		MnSO$_4$ X S = NS	
	ZnSO$_4$ X MnSO$_4$ = 0.001					ZnSO$_4$ X MnSO$_4$ X S = NS			

A preliminary examination of the data (Table 4.18) revealed that the interaction between zinc sulphate and manganese sulphate levels was significant for seed electrical conductivity. The lowest electrical conductivity (0.026 dS m^{-1}) was achieved with $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm having statistical superiority over rest of the combinations while water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) produced the highest value (0.036 dS m^{-1}). All other two factor and three factor interactions were found to be non-significant.

The electrical conductivity of seed is greatly dependent on its vigour. The electrical conductivity of the seed is inversely related to its vigour, since seed vigour is greatest when electrical conductivity is lowest. The decrease in EC with zinc administration can be explained on the fact that this element is known to promote cellwall integrity, reducing soluteleaking from the seed. The results of the present investigation are in agreement with the findings of Kiran (2006) in brinjal. Simrarly, positive effect of the combined application of zinc and manganese on this parameter under present investigation can also be attributed to the fact that there was an increase in seed vigour eventually allowing lesser leakage of the solutes from the seed.

4.18 Zinc content in leaf and seed

Data pertaining to zinc content in leaf and seed of turnip (Tables 4.19 and 4.20) depicted significant impact of zinc levels on this trait. It was observed that maximum zinc content (35.77 ppm in leaf and 49.94 ppm in seed) was recorded following foliar spray of $ZnSO_4$ @ 400 ppm being statistically higher than the remaining levels while minimum (29.46 ppm in leaf and 46.62 ppm in seed) in control ($ZnSO_4$ @ 0 ppm).

The data (Tables 4.19 and 4.20) also reflected significant effect of manganese concentrations on zinc content in leaf and seed of turnip (Tables 4.19 and 4.20). Significantly higher zinc content (34.70 ppm in leaf and 50.77 ppm in seed) was recorded at the highest level of manganese whereas minimum (31.01 ppm in leaf and 46.18 ppm in seed) in control ($MnSO_4$ @ 0 ppm).

However, stages of application and all the two way and three way interactions were found to be non-significant.

The presence of suitable levels of nutrients in the seed is a key aspect in improving crop production quality, which is dependent on the process of absorption and remobilization from other parts of the plant to the seeds. Kobraee (2018) also observed a positive effect of zinc and manganese foliar application on zinc content in leaf and seed in chickpea.

4.19 Manganese content in leaf and seed

An examination of the data (Tables 4.21 and 4.22) pertaining to zinc content in leaf and seed of turnip showed significant effect of manganese levels on this trait. It was observed that maximum manganese content (61.77 ppm in leaf and 37.78 ppm in seed) was obtained with highest level of foliar spray of zinc sulphate while minimum (58.50 ppm inleaf and 35.29 ppm in seed) with water spray ($ZnSO_4$ @ 0 ppm).

The data (Tables 4.21 and 4.22) on manganese content in leaf and seed of turnip demonstrated that manganese levels had a significant influence on the trait. The findings revealed that foliar spray of $MnSO_4$ @ 200 ppm recorded significantly highest value (65.55 ppm leaf and 37.85 ppm in seed) than other levels and lowest (57.42 ppm in leaf and 35.22 ppm in seed) in control ($MnSO_4$ @ 0 ppm). On the other hand, effect of zinc, stages of application and all the two way and three way interactions were found to be non-significant.

In the present investigation, it was found that there was a positive correlation between combined application of Zn and Mn on leaf and seed manganese content. Synergistic effect of interaction between $ZnSO_4$ and $MnSO_4$ for leaf and seed manganese content has also been reported by Kobraee (2018) in chickpea.

Table 4.19: Effect of foliar application of nutrients, stages of application and their interaction on zinc content in leaf (ppm) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	26.65	28.15	31.70	32.45	32.85	33.30	32.75	35.50	37.65
S_2 (60 DAT)	27.51	29.43	33.32	32.65	33.95	34.05	34.05	36.45	38.20
Interaction $ZnSO_4$ ×$MnSO_4$	27.08	28.79	32.51	32.55	33.40	33.68	33.40	35.98	37.93

$MnSO_4$ × Stages of application					$ZnSO_4$ × Stages of application				
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**	**Stages of application**	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	30.62	32.17	34.22	32.33	**S_1 (45 DAT)**	28.83	32.87	35.30	32.33
S_2 (60 DAT)	31.40	33.28	35.19	33.29	**S_2 (60 DAT)**	30.09	33.55	36.23	33.29
Mean $MnSO_4$	31.01	32.72	34.70		**Mean $ZnSO_4$**	29.46	33.21	35.77	

$CD_{(0.05)}$	$ZnSO_4$ = 1.81	$MnSO_4$ = 1.81	S = NS	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
	$ZnSO_4$ X $MnSO_4$ = NS			$ZnSO_4$ X $MnSO_4$ X S = NS	

Table 4.20: Effect of foliar application of nutrients, stages of application and their interaction on zinc content in seed (ppm) in turnip

	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	42.19	46.85	48.85	47.08	49.25	50.52	45.70	49.45	52.10
S_2 (60 DAT)	44.75	47.59	49.50	48.20	50.90	51.20	49.15	50.80	52.44
Interaction $ZnSO_4$ × $MnSO_4$	43.47	47.22	49.18	47.64	50.08	50.86	47.43	50.13	52.27

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	44.99	48.52	50.49	48.00
S_2 (60 DAT)	47.37	49.76	51.05	49.39
Mean $MnSO_4$	46.18	49.14	50.77	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	45.96	48.95	49.08	48.00
S_2 (60 DAT)	47.28	50.10	50.80	49.39
Mean $ZnSO_4$	46.62	49.52	49.94	

$CD_{(0.05)}$	$ZnSO_4$ = 0.90	$MnSO_4$ = 0.90	S = NS	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
	$ZnSO_4$ X $MnSO_4$ = NS			$ZnSO_4$ X $MnSO_4$ X S = NS	

Table 4.21: Effect of foliar application of nutrients, stages of application and their interaction on manganese contentin leaf (ppm) in turnip

	ZnSO₄ 0 ppm			ZnSO₄ 300 ppm			ZnSO₄ 400 ppm		
Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**
S_1 (45 DAT)	55.30	57.00	61.85	56.54	58.44	66.20	57.10	59.34	65.70
S_2 (60 DAT)	56.55	57.35	62.95	59.75	60.43	67.57	59.30	60.20	69.00
Interaction $ZnSO_4$ × $MnSO_4$	55.93	57.18	62.40	58.15	59.44	66.89	58.20	59.77	67.35

$MnSO_4$ × Stages of application

Stages of application	**$MnSO_4$ 0 ppm**	**$MnSO_4$ 100 ppm**	**$MnSO_4$ 200 ppm**	**Mean S**
S_1 (45 DAT)	56.31	58.26	64.58	59.72
S_2 (60 DAT)	58.53	59.33	66.51	61.46
Mean $MnSO_4$	57.42	58.79	65.55	

$ZnSO_4$ × Stages of application

Stages of application	**$ZnSO_4$ 0 ppm**	**$ZnSO_4$ 300 ppm**	**$ZnSO_4$ 400 ppm**	**Mean S**
S_1 (45 DAT)	58.05	60.39	60.71	59.72
S_2 (60 DAT)	58.95	62.58	62.83	61.46
Mean $ZnSO_4$	58.50	61.49	61.77	

$CD_{(0.05)}$	$ZnSO_4$ = 3.13	$MnSO_4$ = 3.13	S = NS	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
	$ZnSO_4$ X $MnSO_4$ = NS			$ZnSO_4$ X $MnSO_4$ X S = NS	

Table 4.22: Effect of foliar application of nutrients, stages of application and their interaction on manganese contentin seed (ppm) in turnip

Stages of application	$ZnSO_4$ 0 ppm			$ZnSO_4$ 300 ppm			$ZnSO_4$ 400 ppm		
	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm
S_1 (45 DAT)	33.82	35.25	35.35	34.09	36.20	37.42	36.20	37.20	38.65
S_2 (60 DAT)	34.35	35.30	37.70	35.75	37.50	38.25	37.10	37.85	39.70
Interaction $ZnSO_4 \times MnSO_4$	34.09	35.28	36.53	34.92	36.85	37.84	36.65	37.53	39.18

$MnSO_4$ × Stages of application

Stages of application	$MnSO_4$ 0 ppm	$MnSO_4$ 100 ppm	$MnSO_4$ 200 ppm	Mean S
S_1 (45 DAT)	34.70	36.22	37.14	36.02
S_2 (60 DAT)	35.73	36.88	38.55	37.06
Mean $MnSO_4$	35.22	36.55	37.85	

$ZnSO_4$ × Stages of application

Stages of application	$ZnSO_4$ 0 ppm	$ZnSO_4$ 300 ppm	$ZnSO_4$ 400 ppm	Mean S
S_1 (45 DAT)	34.81	35.90	37.35	36.02
S_2 (60 DAT)	35.78	37.17	38.22	37.06
Mean $ZnSO_4$	35.29	36.53	37.78	

$CD_{(0.05)}$	$ZnSO_4$ = 1.06	$MnSO_4$ = 1.06	S = NS	$ZnSO_4$ X S = NS	$MnSO_4$ X S = NS
	$ZnSO_4$ X $MnSO_4$ = NS			$ZnSO_4$ X $MnSO_4$ X S = NS	

4.20 Economics of seed production in turnip

The data pertaining to economics of different treatment combinations for seed production of turnip have been presented in Table 4.23. It was observed that maximum gross return (₹ 421000), net return (₹ 300627) and B: C ratios (2.49:1) were registered in treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT and least profitable treatment combination was in $ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT having minimum gross return (₹ 306500), net return (₹ 187627) and B:C ratio (1.57:1).

B: C ratio of treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT was high due to the reason that seed yield contributing parameters such as number of seeds siliqua^{-1}, number of siliquae plant^{-1}, 1000 seed weight and seed yieldplot^{-1} were maximum in the above interaction which led to maximum seed yield ha^{-1}. The highest seed yield resulted in the highest gross and net returns, resulting in the highest B:C ratio.

Table 4.23: Economics of seed production in turnip

Sr. No.	Treatment code	Total cost	Yield / ha (q)	Gross return	Net return	B : C ratio
1	$Z_0M_0S_1$	118873	6.13	306500	187627	1.57:1
2	$Z_0M_0S_2$	118873	6.28	314000	195127	1.64:1
3	$Z_0M_1S_1$	119123	6.35	317500	198377	1.66:1
4	$Z_0M_1S_2$	119123	6.54	327000	207877	1.74:1
5	$Z_0M_2S_1$	119373	6.63	331500	212127	1.77:1
6	$Z_0M_2S_2$	119373	6.77	338500	219127	1.83:1
7	$Z_1M_0S_1$	119623	6.62	331000	211377	1.76:1
8	$Z_1M_0S_2$	119623	6.70	335000	215377	1.80:1
9	$Z_1M_1S_1$	119873	7.26	363000	243127	2.02:1
10	$Z_1M_1S_2$	119873	7.56	378000	258127	2.15:1
11	$Z_1M_2S_1$	120123	7.86	393000	272877	2.27:1
12	$Z_1M_2S_2$	120123	8.04	402000	281877	2.34:1
13	$Z_2M_0S_1$	119873	6.98	349000	229127	1.91:1
14	$Z_2M_0S_2$	119873	7.15	357500	237627	1.98:1
15	$Z_2M_1S_1$	120123	7.78	389000	268877	2.23:1
16	$Z_2M_1S_2$	120123	8.15	407500	287377	2.39:1
17	$Z_2M_2S_1$	120373	8.31	415500	295127	2.45:1
18	$Z_2M_2S_2$	120373	8.42	421000	300627	2.49:1

Chapter – 5

SUMMARY AND CONCLUSION

The current investigation titled, **"Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip"** was conducted during rabi 2021-22 at the Experimental Farm and Laboratory of the Department of Seed Science and Technology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP. The field experiment was designed with three replications in Randomized Block Design (RBD) whereas the laboratory studies were carried out with four replications in Completely Randomized Design (CRD). In the research, the variety 'Purple Top White Globe' was used. Turnip seeds were planted in October and in December, the roots were uprooted and the stecklings were replanted in plots of size 1.8 x 1.8 m at 45 × 30 cm spacing. The various growth and seed parameters recorded were plant height (cm), plant spread (cm), number of siliquae plant^{-1}, siliqua length (cm), number of seeds siliqua^{-1}, days taken to seed maturity, seed yield (g plant^{-1}, g plot^{-1} and kg ha^{-1}) and plant biomass (q ha^{-1}). The seed quality attributes were 1000 seed weight (g), germination (%) of harvested seed, speed of germination, seedling length (cm), seedling dry weight (mg), seed vigour index-I, seed vigour index-II, electrical conductivity (dS m^{-1}) and nutrient content in above ground part and seed (Zn and Mn in ppm). The results obtained have been summarized below.

5.1 EFFECT OF FOLIAR APPLICATION OF ZINC, MANGANESE, STAGES OF APPLICATION AND THEIR INTERACTION ON GROWTH AND YIELD OF TURNIP

The foliar spray of $ZnSO_4$ @ 400 ppm showed significantly higher plant height (152.05 cm), plant spread (79.68 cm), number of siliquae plant^{-1} (1198.21), siliqua length (8.01 cm), number of seeds siliqua^{-1} (19.67), seed yield (19.04 g plant^{-1} , 316.08 g plot^{-1} and 780.44 kg ha^{-1}) and plant biomass (42.69 q ha^{-1}). On the other hand, minimum figures for these traits were observed in control ($ZnSO_4$ @ 0 ppm).

Among manganese levels, $MnSO_4$ @ 200 ppm resulted in maximum plant height (151.92 cm), plant spread (79.53 cm), number of siliquae plant^{-1} (1182.14), siliqua length (8.03 cm), number of seeds siliqua^{-1} (19.09), seed yield (18.20 g plant^{-1}, 310.86 g plot^{-1} and 767.56 kg ha^{-1}) and plant biomass (41.21 q ha^{-1}). However, minimum values for these parameters were recorded in control ($MnSO_4$ @ 0 ppm).

The effect of foliar application of chemicals at different stages *i.e.*, 45 and 60 days after transplanting showed a significant increase in plant height (149.37 cm) and plant spread (77.41 cm) at 45 DAT as compared to 60 DAT while number of siliquae plant^{-1} (1138.96), siliqua length (7.81 cm), number of seeds siliqua^{-1} (17.64), seed yield (18.79 g plant^{-1}, 295.46 g plot^{-1} and 729.54 kg ha^{-1}) and plant biomass (38.80 q ha^{-1}) had highest values at 60 days after transplanting. However, application at 45 DAT had lowest values for these parameters.

For the interaction between $ZnSO_4$ and $MnSO_4$ levels, foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm resulted in highest plant height (155.19 cm), plant spread (82.10 cm), number of siliquae plant^{-1} (1235.29), siliqua length (8.21 cm), number of seeds siliqua^{-1} (22.39), seed yield (20.70 g plant^{-1}, 338.92 g plot^{-1} and 836.84 kg ha^{-1}) and plant biomass (45.84 q ha^{-1}). The lowest values for these traits were seen by using water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm).

The two-way interaction between $ZnSO_4$ × S resulted in significantly higher number of siliquae plant^{-1} (1203.22), number of seeds siliqua^{-1} (20.02), seed yield (19.44 g plant^{-1} 320.48 g plot^{-1} and 791.30 kg ha^{-1}) with spray of $ZnSO_4$ @ 400 ppm at 60 DAT while minimum in control ($ZnSO_4$ @ 0 ppm at 45 DAT). In contrast, the effect on plant height, plant spread, siliqua length and plant biomass was found to be non-significant.

The interaction between $MnSO_4$ × S was also found to be significant having highest number of siliquae plant^{-1} (1184.91), number of seeds siliqua^{-1} (19.35), seed yield (18.79 g plant^{-1}, 313.84 g plot^{-1} and 774.91 kg ha^{-1}) following application of $MnSO_4$ @ 200 ppm at 60 DAT.On the other hand, minima for these parameters were attained in control ($MnSO_4$ @ 0 ppm at 45 DAT). Contrary to this, the effect on plant height, plant spread, siliqua length and plant biomass was found to be non-significant.

The three-way interaction of $ZnSO_4$ × $MnSO_4$ × S influenced the parameters studied significantly resulting in maximum plant height (155.65 cm) and plant spread (82.17 cm) with foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 DAT. However, highest number of siliquae plant^{-1} (1238.07), number of seeds siliqua^{-1} (22.63), seed yield (21.19 g plant^{-1}, 341.29 g plot^{-1} and 842.68 kg ha^{-1}) were obtained in treatment combination, $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm applied at 60 DAT whereas lowest figures for these characters wereobserved with water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT). The impact on siliqua length and plant biomass was discovered to be non-significant.

5.2 EFFECT ON SEED QUALITY PARAMETERS

Spray of $ZnSO_4$ @ 400 ppm significantly increased 1000 seed weight (1.76 g), germination (92.46 %), speed of germination (11.62), seedling length (16.88 cm), seedling dry weight (10.20 mg), seed vigour index-I (1564.45), seed vigour index-II (942.03) along with minimum electrical conductivity (0.028 dS m^{-1}) whereas control ($ZnS0_4$ @ 0 ppm) produced the lowest values for these traits.

The foliar application of $MnSO_4$ at various levels in turnip also had significant influence recording maximum 1000 seed weight (1.75 g), germination (92.20 %), speed of germination (11.53), seedling length (16.66 cm), seedling dry weight (10.40 mg), seed vigour index-I (1539.94), seed vigour index-II (943.78) and least electrical conductivity (0.030 dS m^{-1}) with $MnSO_4$ @ 200 ppm while water spray ($MnSO_4$ @ 0 ppm) recorded least figures for these parameters.

Out of the two stages of application, foliar spray of micronutrients on turnip at 60 DAT resulted in significantly higher 1000 seed weight (1.73 g), germination (91.18 %), speed of germination (11.26), seedling length (15.57 cm), seedling dry weight (9.65 mg), seed vigour index-I (1425.25), seed vigour index-II (891.25) and lowest electrical conductivity (0.031 dS m^{-1}) in comparison to the spray given at 45 DAT.

The cumulative influence of various levels of zinc sulphate and manganese sulphate was found to be significant and highest 1000 seed weight (1.81 g), germination (94.51 %), speed of germination (12.38), seedling length (18.74 cm), seedling dry weight (11.52 mg), seed vigour index-I (1771.13), seed vigour index-II (1087.07) and minimum electrical conductivity (0.026 dS m^{-1}) were observed with foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm. Contrarily, water spray ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm) had lowest values for these characters.

Spraying $ZnSO_4$ @ 400 ppm at 60 DAT significantly increased germination (92.96 %), germination speed (11.84), seedling length (17.31 cm) and seed vigour index-I (1612.25) while minimum figures were obtained in control ($ZnSO_4$ @ 0 ppm at 45 DAT). However, influence on seedling dry weight, SVI-II and electrical conductivity was found to be non-significant.

Significantly higher values of germination (92.76 %), speed of germination (11.75), seedling length (16.95 cm) and seed vigour index-I (1575.81) were recorded with $MnSO_4$ @ 200 ppm at 60 DAT as compared to water spray ($MnSO_4$ @ 0 ppm at 45 DAT). On the other hand, it was discovered that the influence on seedling dry weight, SVI-II and electrical conductivity was non-significant.

The overall effect of $ZnSO_4 \times MnSO_4 \times S$ exhibited significantly higher values for germination (94.86 %), speed of germination (12.58), seedling length (18.89 cm) and seed vigour index-I (1792.53) with combined spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT. The lowest values were obtained in control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT). Contrary to this, the effect on seedling dry weight, SVI-II and electrical conductivity was found to be non-significant.

5.3 EFFECT ON NUTRIENT CONTENT (Zn and Mn in ppm)

Foliar spray of $ZnSO_4$ @ 400 ppm showed maximum zinc content (35.77 ppm in leaf and 49.94 ppm in seed) and manganese content (34.70 ppm in leaf and 50.77 ppm in seed) at highest level and lowest values were obtained with $ZnSO_4$ @ 0 ppm. The cumulative effect of $ZnSO_4 \times MnSO_4$, $ZnSO_4 \times S$, $MnSO_4 \times S$ and $ZnSO_4 \times MnSO_4 \times S$ was found to be non- significant.

In a similar fashion, foliar application of $MnSO_4$ @ 200 ppm resulted in significantly higher zinc content (61.77 ppm in leaf and 37.78 ppm in seed) as well as manganese content (65.55 ppm leaf and 37.85 ppm in seed) while minimal was observed in control ($MnSO_4$ @ 0 ppm). However, the combined influence of $ZnSO_4 \times MnSO_4$, $ZnSO_4 \times S$, $MnSO_4 \times S$ and $ZnSO_4 \times MnSO_4 \times S$ were determined to be non-significant.

5.4 ECONOMICS OF SEED PRODUCTION IN TURNIP

Out of different treatment combinations, highest B: C ratio (2.49:1) was calculated in treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT. However, minimum B: C ratio was observed in control ($ZnSO_4$ @ 0 ppm + $MnSO_4$ @ 0 ppm at 45 DAT).

CONCLUSION

Based on the findings, it is concluded treatment combination, $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT, outperformed other interactions for majority of the growth, seed yield as well as quality parameters *viz.*, siliquae plant^{-1}, siliqua length, seeds siliqua^{-1}, seed yield and quality attributes in laboratory *i.e.*, 1000 seed weight, speed of germination, germination percentage, seedling length, seedling dry weight, seed vigour index-I, seed vigour index-II along with lowest seed electrical conductivity. This treatment combination also resulted in the highest B: C ratio (2.49: 1). Hence, for getting higher yield of quality seed in turnip under mid hill conditions of Himachal Pradesh, foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT can be recommended after multi-location testing.

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APPENDIX-I

Mean monthly meteorological data w. e. f. September 2021 to April 2022

Month	Rainfall (mm)	Maximum Temperature (ºC)	Minimum Temperature (ºC)	Mean Temperature (ºC)	Relative Humidity (%)
September 2021	218.3	28.2	18.9	23.6	79.0
October 2021	52.6	27.1	11.8	19.5	66.0
November 2021	0.0	23.9	4.8	14.5	54.0
December 2021	14.3	18.6	2.3	10.5	61.0
January 2022	26.1	16.1	3.2	9.7	58.0
February 2022	82.7	18.8	2.7	10.8	55.0
March 2022	0.0	27.6	9.4	18.5	44.0
April 2022	1.0	33.2	13.3	23.3	37.0

Source: Meteorological Observatory, Department of Environmental Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173 230

APPENDIX-II

Effect of zinc levels, manganese levels, stages of application and their interaction on growth and seed yield parameters in turnip

Analysis of variance table for plant height (cm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	0.440		
Zinc levels (Zn)	2	494.809	247.405	346.744
Manganese levels (Mn)	2	424.405	212.202	297.407
Zn X Mn	4	50.122	12.530	17.562
Stages of application (S)	1	30.493	30.493	42.736
Zn X S	2	5.826	2.913	4.083
Mn X S	2	2.405	1.203	1.686
Zn X Mn X S	4	11.803	2.951	4.136
Error	34	24.259	0.714	
Total	53	1,044.563		

Analysis of variance table for plant spread (cm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	5.760		
Zinc levels (Zn)	2	291.668	145.834	233.782
Manganese levels (Mn)	2	311.846	155.923	249.956
Zn X Mn	4	8.076	2.019	3.237
Stages of application (S)	1	6.864	6.864	11.003
Zn X S	2	0.355	0.178	0.285
Mn X S	2	2.267	1.134	1.817
Zn X Mn X S	4	10.208	2.552	4.091
Error	34	21.209	0.624	
Total	53	658.254		

Analysis of variance table for number of siliquae plant^{-1}

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	268.455		
Zinc levels (Zn)	2	203,442.325	101,721.163	1,933.186
Manganese levels (Mn)	2	134,907.181	67,453.590	1,281.939
Zn X Mn	4	26,392.632	6,598.158	125.396
Stages of application (S)	1	5,384.488	5,384.488	102.331
Zn X S	2	1,648.114	824.057	15.661
Mn X S	2	2,110.025	1,055.012	20.050
Zn X Mn X S	4	2,335.111	583.778	11.095
Error	34	1,789.026	52.618	
Total	53	378,277.356		

Analysis of variance table for siliqua length (cm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	0.028		
Zinc levels (Zn)	2	2.526	1.263	78.245
Manganese levels (Mn)	2	4.889	2.445	151.420
Zn X Mn	4	0.387	0.097	5.994
Stages of application (S)	1	0.309	0.309	19.159
Zn X S	2	0.023	0.011	0.704
Mn X S	2	0.006	0.003	0.193
Zn X Mn X S	4	0.003	0.001	0.048
Error	34	0.549	0.016	
Total	53	8.721		

Analysis of variance table for number of seeds siliqua^{-1}

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	0.023		
Zinc levels (Zn)	2	254.727	127.364	6,616.701
Manganese levels (Mn)	2	147.620	73.810	3,834.532
Zn X Mn	4	42.378	10.594	550.398
Stages of application (S)	1	4.641	4.641	241.082
Zn X S	2	0.110	0.055	2.867
Mn X S	2	0.641	0.320	16.648
Zn X Mn X S	4	0.307	0.077	3.990
Error	34	0.654	0.019	
Total	53	451.102		

Analysis of variance table for days taken to seed maturity

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	21.771		
Zinc levels (Zn)	2	28.838	14.419	0.856
Manganese levels (Mn)	2	11.892	5.946	0.353
Zn X Mn	4	43.070	10.767	0.639
Stages of application (S)	1	0.426	0.426	0.025
Zn X S	2	19.108	9.554	0.567
Mn X S	2	4.374	2.187	0.130
Zn X Mn X S	4	42.707	10.677	0.634
Error	34	572.617	16.842	
Total	53	744.803		

Analysis of variance table for seed yield (g $plant^{-1}$)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	0.045		
Zinc levels (Zn)	2	270.653	135.327	5,131.711
Manganese levels (Mn)	2	117.490	58.745	2,227.656
Zn X Mn	4	9.013	2.253	85.441
Stages of application (S)	1	14.178	14.178	537.654
Zn X S	2	0.545	0.273	10.335
Mn X S	2	0.245	0.122	4.638
Zn X Mn X S	4	0.585	0.146	5.550
Error	34	0.897	0.026	
Total	53	413.651		

Analysis of variance table for seed yield (g $plot^{-1}$)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	3.739		
Zinc levels (Zn)	2	27,862.630	13,931.315	27,528.361
Manganese levels (Mn)	2	15,838.393	7,919.196	15,648.379
Zn X Mn	4	2,294.484	573.621	1,133.478
Stages of application (S)	1	788.913	788.913	1,558.897
Zn X S	2	13.056	6.528	12.899
Mn X S	2	105.512	52.756	104.246
Zn X Mn X S	4	43.866	10.966	21.670
Error	34	17.206	0.506	
Total	53	46,967.799		

Analysis of variance table for seed yield (kg ha^{-1})

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	25.520		
Zinc levels (Zn)	2	169,871.029	84,935.514	28,199.511
Manganese levels (Mn)	2	96,566.916	48,283.458	16,030.631
Zn X Mn	4	13,984.678	3,496.170	1,160.766
Stages of application (S)	1	4,811.041	4,811.041	1,597.318
Zn X S	2	77.914	38.957	12.934
Mn X S	2	643.676	321.838	106.854
Zn X Mn X S	4	266.796	66.699	22.145
Error	34	102.406	3.012	
Total	53	286,349.976		

Analysis of variance table for plant biomass (q ha^{-1})

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	9.496		
Zinc levels (Zn)	2	896.295	448.148	181.520
Manganese levels (Mn)	2	314.711	157.355	63.736
Zn X Mn	4	35.812	8.953	3.626
Stages of application (S)	1	17.875	17.875	7.240
Zn X S	2	0.512	0.256	0.104
Mn X S	2	0.430	0.215	0.087
Zn X Mn X S	4	4.751	1.188	0.481
Error	34	83.941	2.469	
Total	53	1,363.823		

APPENDIX-III

Effect of zinc levels, manganese levels, stages of application and their interaction on seed quality parameters in turnip

Analysis of variance table for 1000 seed weight (g)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Replications	2	0.003		
Zinc levels (Zn)	2	0.105	0.052	151.238
Manganese levels (Mn)	2	0.063	0.032	91.222
Zn X Mn	4	0.006	0.002	4.611
Stages of application (S)	1	0.005	0.005	15.525
Zn X S	2	0.001	0.000	0.815
Mn X S	2	0.000	0.000	0.521
Zn X Mn X S	4	0.001	0.000	0.528
Error	34	0.012	0.000	
Total	53	0.196		

Analysis of variance table for germination (%) of harvested seed

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	0.358	0.179	4,462.063
Manganese levels (Mn)	2	0.271	0.136	3,385.997
Zn X Mn	4	0.057	0.014	352.519
Stages of application (S)	1	0.045	0.045	1,128.885
Zn X S	2	0.011	0.006	137.448
Mn X S	2	0.000	0.000	0.759
Zn X Mn X S	4	0.004	0.001	26.750
Error	34	0.001	0.000	
Total	53	0.748		

Analysis of variance table for speed of germination

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	11.298	5.649	271.316
Manganese levels (Mn)	2	10.246	5.123	246.058
Zn X Mn	4	1.830	0.457	21.971
Stages of application (S)	1	2.320	2.320	111.434
Zn X S	2	0.194	0.097	4.648
Mn X S	2	0.072	0.036	1.718
Zn X Mn X S	4	0.307	0.077	3.692
Error	36	0.750	0.021	
Total	53	27.017		

Analysis of variance table for seedling length (cm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	172.068	86.034	3,480.107
Manganese levels (Mn)	2	67.904	33.952	1,373.375
Zn X Mn	4	5.657	1.414	57.212
Stages of application (S)	1	7.201	7.201	291.265
Zn X S	2	0.136	0.068	2.750
Mn X S	2	0.211	0.105	4.259
Zn X Mn X S	4	1.117	0.279	11.292
Error	36	0.890	0.025	
Total	53	255.183		

Analysis of variance table for seedling dry weight (mg)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	18.916	9.458	34.046
Manganese levels (Mn)	2	35.218	17.609	63.385
Zn X Mn	4	3.916	0.979	3.524
Stages of application (S)	1	2.105	2.105	7.577
Zn X S	2	0.204	0.102	0.367
Mn X S	2	0.449	0.225	0.809
Zn X Mn X S	4	0.488	0.122	0.439
Error	36	10.001	0.278	
Total	53	71.298		

Analysis of variance table for seed vigour index-I

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	1,827,461.457	913,730.729	4,336.152
Manganese levels (Mn)	2	804,653.876	402,326.938	1,909.261
Zn X Mn	4	82,631.771	20,657.943	98.033
Stages of application (S)	1	95,086.722	95,086.722	451.238
Zn X S	2	3,729.424	1,864.712	8.849
Mn X S	2	1,663.594	831.797	3.947
Zn X Mn X S	4	13,196.056	3,299.014	15.656
Error	36	7,586.059	210.724	
Total	53	2,836,008.959		

Analysis of variance table for seed vigour index-II

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	223,920.728	111,960.364	35.733
Manganese levels (Mn)	2	224,710.973	112,355.487	35.859
Zn X Mn	4	142,184.610	35,546.153	11.345
Stages of application (S)	1	39,701.011	39,701.011	12.671
Zn X S	2	1,056.326	528.163	0.169
Mn X S	2	8,364.661	4,182.330	1.335
Zn X Mn X S	4	2,528.427	632.107	0.202
Error	36	112,795.947	3,133.221	
Total	53	755,262.682		

Analysis of variance table for seed electrical conductivity (dS m^{-1})

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	0.0002	0.0001	288.353
Manganese levels (Mn)	2	0.0002	0.0001	67.228
Zn X Mn	4	0.0001	0.0001	12.199
Stages of application (S)	1	0.0001	0.0001	1.034
Zn X S	2	0.000	0.000	15.685
Mn X S	2	0.000	0.000	1.796
Zn X Mn X S	4	0.000	0.000	4.887
Error	36	0.0001	0.000	
Total	53	0.001		

Analysis of variance table for zinc content in leaves (ppm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	91.266	45.633	6.969
Manganese levels (Mn)	2	150.756	75.378	11.511
Zn X Mn	4	44.158	11.039	1.686
Stages of application (S)	1	1.550	1.550	0.237
Zn X S	2	42.008	21.004	3.208
Mn X S	2	6.324	3.162	0.483
Zn X Mn X S	4	16.180	4.045	0.618
Error	36	235.733	6.548	
Total	53	587.974		

Analysis of variance table for manganese content in leaves (ppm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	307.957	153.979	6.986
Manganese levels (Mn)	2	329.422	164.711	7.473
Zn X Mn	4	80.607	20.152	0.914
Stages of application (S)	1	0.027	0.027	0.001
Zn X S	2	0.379	0.189	0.009
Mn X S	2	31.750	15.875	0.720
Zn X Mn X S	4	106.161	26.540	1.204
Error	36	793.443	22.040	
Total	53	1,649.746		

Analysis of variance table for zinc content in seeds (ppm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	81.906	40.953	11.967
Manganese levels (Mn)	2	77.928	38.964	11.386
Zn X Mn	4	17.169	4.292	1.254
Stages of application (S)	1	0.547	0.547	0.160
Zn X S	2	0.844	0.422	0.123
Mn X S	2	9.741	4.870	1.423
Zn X Mn X S	4	70.312	17.578	5.136
Error	36	123.198	3.422	
Total	53	381.645		

Analysis of variance table for manganese content in seed (ppm)

Source of Variation	df	Sum of Squares	Mean Squares	F-Calculated
Zinc levels (Zn)	2	70.135	35.067	14.821
Manganese levels (Mn)	2	34.660	17.330	7.325
Zn X Mn	4	22.636	5.659	2.392
Stages of application (S)	1	1.765	1.765	0.746
Zn X S	2	5.772	2.886	1.220
Mn X S	2	2.494	1.247	0.527
Zn X Mn X S	4	17.199	4.300	1.817
Error	36	85.176	2.366	
Total	53	239.837		

APPENDIX-IV

Benefit: Cost ratio of different treatment combinations in seed production of turnip

A. Fixed cost

Rental charges @ ₹ 2000/ month = 2000 x 8 = ₹ 16,000

Sr. No.	Operation / Particulars	Unit	Price / Unit (₹)	Total Amount (₹)
	Production of mother roots			
1.	**Field preparation**			
	2 ploughing with tractor	3 hours	500/-	3000.00
	2 planking	1.5 hours	250/-	500.00
	Land preparation	20 man days	300/-	6000.00
2.	**Manure and fertilizers**			
	FYM	1000 kg	185/100 kg	18500.00
	Urea	50 kg	254/50 kg	254.00
	SSP	300 kg	495/50 kg	2974.00
	MOP	60 kg	850/50 kg	1020.00
	Labour for manure and fertilizer	10 man days	300/-	3000.00
3.	**Seed rate**	4 kg	500/kg	2000.00
	Seed sowing	20 man days	300 /-	6000.00
4.	**Intercultural Operation**			
	Earthing up	15 man days	300/-	4500.00
	Irrigation	10 man days	300/-	3000.00
	Plant protection	10 man days	300/-	3000.00
5.	**Harvesting**	20 man days	300/-	6000.00
6.	**Uprooting of roots**	20 man days	300/-	6000.00
	Replanting of stecklings			
7.	**Preparation of stecklings**	20 man days	300/-	6000.00
8.	**Field preparation**			
	Ploughing with tractor	3 hours	500/-	1500.00
	Preparation of beds	20 man days	300/-	6000.00
9.	**Replanting of stecklings**	20 man days	300/-	6000.00
10.	**Intercultural operations**			
	Earthening up	20 man days	300/-	6000.00
	Irrigation	10 man days	300/-	3000.00
11.	**Harvesting of seeds**	20 man days	300/-	6000.00
12.	**Extraction of seeds**	15 man days	300/-	4500.00
13.	**Packaging of seeds**	10 man days	300/-	3000.00
	Total expenditure			**1,17,748.00**

B. Variable cost

For spray 10 labour used for 3 hours = ₹ 1125.00

Treatment combination	Item	Unit	Total Amount (₹)
$Z_0M_0S_1$	Water Spray	Water	0.00
$Z_0M_0S_2$	Water Spray	Water	0.00
$Z_0M_1S_1$	$MnSO_4$ @ 100 ppm at 45 DAT	250 g	250 .00
$Z_0M_1S_2$	$MnSO_4$ @ 100 ppm at 60 DAT	250 g	250.00
$Z_0M_2S_1$	$MnSO_4$ @ 200 ppm at 45 DAT	500 g	500.00
$Z_0M_2S_2$	$MnSO_4$ @ 200 ppm at 60 DAT	500 g	500.00
$Z_1M_0S_1$	$ZnSO_4$ @ 300 ppm at 45 DAT	750 g	750.00
$Z_1M_0S_2$	$ZnSO_4$ @ 300 ppm at 60 DAT	750 g	750.00
$Z_1M_1S_1$	$ZnSO_4$ @ 300 ppm + $MnSO_4$ @ 100 ppm at 45 DAT	750 g $ZnSO_4$ + 250 g $MnSO_4$	1000.00
$Z_1M_1S_2$	$ZnSO_4$ @ 300 ppm + $MnSO_4$ @ 100 ppm at 60 DAT	750 g $ZnSO_4$ + 250 g $MnSO_4$	1000.00
$Z_1M_2S_1$	$ZnSO_4$ @ 300 ppm + $MnSO_4$ @ 200 ppm at 45 DAT	750 g $ZnSO_4$ + 500 g $MnSO_4$	1250.00
$Z_1M_2S_2$	$ZnSO_4$ @ 300 ppm + $MnSO_4$ @ 200 ppm at 60 DAT	750 g $ZnSO_4$ + 500 g $MnSO_4$	1250.00
$Z_2M_0S_1$	$ZnSO_4$ @ 400 ppm at 45 DAT	1000 g	1000.00
$Z_2M_0S_2$	$ZnSO_4$ @ 400 ppm at 60 DAT	1000 g	1000.00
$Z_2M_1S_1$	$ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 100 ppm at 45 DAT	1000 g $ZnSO_4$ + 250 g $MnSO_4$	1250.00
$Z_2M_1S_2$	$ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 100 ppm at 60 DAT	1000 g $ZnSO_4$ + 250 g $MnSO_4$	1250.00
$Z_2M_2S_1$	$ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 DAT	1000 g $ZnSO_4$ + 500 g $MnSO_4$	1500.00
$Z_2M_2S_2$	$ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT	1000 g $ZnSO_4$ + 500 g $MnSO_4$	1500.00

Seed price = ₹ 500/kg

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Title of the Thesis	**:**	**Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip**
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Admission Number	**:**	H-2020-85-M
Major Advisor	**:**	Dr Rajender Sharma
Major Discipline	**:**	Seed Science and Technology
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ABSTRACT

The present investigation titled, "Studies on the effect of micronutrients on seed yield, quality and nutrient uptake in turnip" was undertaken at Pandah Experimental Farm of the Department of Seed Science and Technology, Dr Y S Parmar University of Horticulture and Forestry Nauni, Solan HP during rabi season of 2021-2022 using turnip cv. Purple Top White Globe. There were eighteen treatment combinations which included three levels each of zinc (0, 300 and 400 ppm $ZnSO_4$) and manganese (0, 100 and 200 ppm $MnSO_4$) along with two stages of application (45 and 60 DAT) replicated thrice in RBD. Each plot of size 1.8 × 1.8 m accommodated twenty four plants ata spacing of 45 × 30 cm. The results revealed that out of 18 treatment combinations, $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 45 DAT was best for growth parameters resulting in maximum plant height (155.65 cm) and plant spread (82.17 cm). On the other hand, treatment combination $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT outperformed rest of the interactions by registering maxima for number of siliquae plant^{-1} (1238.07), siliqua length (8.28 cm), number of seeds siliqua^{-1} (22.63), seed yield (21.19 g plant^{-1}, 341.29 g plot^{-1} and 842.68 kg ha^{-1}), plant biomass (45.87 q ha^{-1}), 1000 seed weight (1.82 g), speed of germination (12.58), germination (94.86 %), seedling length (18.90 cm), seedling dry weight (11.57 mg), seed vigour index-I (1792.54), seed vigour index-II (1088.61) along with lowest figures for seed electrical conductivity (0.025 dS m^{-1}) and days to seed maturity (120.46). This treatment combination also ensured highest B: C ratio (2.49: 1). Similarly, highest levels of both the micronutrients tested recorded significantly higher leaf and seed nutrient content (Zn and Mn); though there interaction could not influence these traits. Hence, foliar spray of $ZnSO_4$ @ 400 ppm + $MnSO_4$ @ 200 ppm at 60 DAT can be recommended for higher seed yield andquality of turnip under mid-hill situation of Himachal Pradesh after multi-location testing.

Signature of Student — **Signature of Major Advisor**
Name: Prashant Panghal — **Dr Rajender Sharma**

Countersigned

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