INFLUENCE OF MICRONUTRIENTS AND APPLICATION METHOD ON GROWTH, YIELD AND OIL CONTENT OF SUNFLOWER (*Helianthus annuus* L.)

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CERTIFICATE

*This is to certify that the thesis entitled, "**INFLUENCE OF MICRONUTRIENTS AND APPLICATION METHOD ON GROWTH, YILED AND OIL CONTENT OF SUNFLOWER (Helianthus annuus*** **L.)"** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of* ***MASTER OF SCIENCE (MS) in AGRONOMY****, embodies the result of a piece of bona-fide research work carried out by* ***MD. SAKIBUL ALAM,*** *Registration no.* ***19-10348*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December, 2021

Place: Dhaka, Bangladesh

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Dedicated

To

My Beloved Parents

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INFLUENCE OF MICRONUTRIENTS AND APPLICATION METHOD ON GROWTH, YIELD AND OIL CONTENT OF SUNFLOWER (*Helianthus annuus* L.)

ABSTRACT

The field experiment was conducted at the research field of Department of Agronomy, Sher-e-Bangla Agricultural University (SAU) during the period of November, 2020 to April 2021 to evaluate the influence of soil and foliar applied micronutrients (B, Mn, Zn) on sunflower for improving physiological traits, yield and oil content. The experiment consisted of micronutrient application method and micronutrient combination. The application methods were F_1 = Soil application of micronutrient and F_2= Foliar application of micronutrient. The 7 micronutrient treatments were T_1= Boron, T_2= Manganese, T_3= Zinc T_4= Boron+ Manganese T_5= Boron+ Zinc T_6= Manganese+ Zinc and T_7= Boron+ Manganese+ Zinc. The foliar micronutrient application rate was H_3BO_4= 0.5 g L^{-1} or @ 0.5%, $MnSO_4$= 1 g L^{-1} or @ 1% and $ZnSO_4$= 2 g L^{-1} or @ 2% and applied at 30 days after sowing (DAS), 50 DAS and 70 DAS. Micronutrients were applied, boron as boric acid (12 kg ha^{-1}), zinc as zinc sulphate (10 kg ha^{-1}) and manganese as manganese sulphate (12 kg ha^{-1}) during final land preparation. The recommended dose of N as Urea, P as TSP and K as MoP (180:150:120 kg ha^{-1}) were applied along with soil application and foliar application of micronutrient. The experiment was laid out in a RCBD factorial design with three replications. The result revealed that, F_2 (foliar application) showed significantly better crop growth like plant height at all the growth stages, number of leaf $plant^{-1}$, leaf area index, dry matter weight, relative water content and yield contributing traits like head diameter (13.7 cm), seed $head^{-1}$ (20.37), stover yield (55.12 g $plant^{-1}$), seed yield (20.37 g $plant^{-1}$), biological yield (87.86 g), harvest index (31.03%) and protein percentage (44.4%). The micronutrient treatment T_5= (B+ Zn), T_6 (B+ Mn) and T_7 (B+ Mn+ Zn) showed the better performance in different yield contributing parameters. Treatment interaction of micronutrients with foliar application showed better results in yield components like head diameter, 1000 seed weight, seed $head^{-1}$, seed yield, stover yield, biological yield, harvest index, oil percentage and protein percentage.

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LIST OF ABBREVIATIONS

ABBREVIATION	ELABORATION
%	Percentage
@	At the rate of
° C	Degree Centigrade
AEZ	Agroecological Zones
ANOVA	Analysis of Variance
B	Boron
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
CGR	Crop Growth Rate
cm	Centi-meter
CV (%)	Percent Coefficient of Variance
DAS	Days After Sowing
DAT	Days After Transplanting
DMC	Dry matter content
DMW	Dry matter weight
DW	Dry weight
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agriculture Organization
FYM	Farmyard manure
FW	Fresh weight
g	Gram (s)
h	hour
ha	hectare
HI	Harvest index (%)
IAA	Indole-3-Acetic Acid
K	Kalium (Latin name for potassium)
Kg	Kilogram
L.	Linnaeus
L^{-1}	Per liter
LAI	Leaf Area Index
LAR	Leaf Area Ratio
LSD	Least Significance Variance
M.S.	Master of Science
m^2	Meter squares
m^{-2}	Per meter squares
meq	milliequivalent

LIST OF ABBREVIATIONS (Cont'd)

ABBREVIATION	ELABORATION
mg	Milligram
Mn	Manganese
MoP	Muriate of potash
NGR	National Grower Register
P	Phosphorus
pH	Potential of Hydrogen
ppm	Parts per million
RCBD	Randomized Complete Block Design
RGR	Relative Growth Rate
RNA	Ribonucleic acid
RWC	Relative water content
SAU	Sher-e-Bangla Agricultural University
SPAD	Soil Plant Analysis Value
SRDI	Soil Resource Development Institute
$t\ ha^{-1}$	Ton per hectare
TDM	Total dry matter
TSP	Triple superphosphate
TW	Turgid weight
UNDP	United Nations Development Programme
USA	United States of America
USSR	United Soviet Socialist Republic
YOL	Youngest opened leaf
Zn	Zinc

CHAPTER I

INTRODUCTION

Micronutrients are essential elements that are used by plants in small quantities. Both micronutrients and macronutrients play vital roles in essential and physiological functions of plant metabolism (Epstein,1965; Marschner,1986). For the growth of plants micro nutrients are required in lower amounts compared with macro nutrients. It mainly serves as activator of enzyme reactions. There are seven essential plant nutrient elements defined as micronutrients. They are Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Molybdenum (Mo), Chlorine (Cl). They constitute in total less than 1% of the dry weight of most plants.

Yield and quality of agricultural products increased with micronutrients applications. The incidence of micronutrient deficiencies in crop has increased markedly in recent years due to intensive cropping, loss of top soil by erosions, losses of micronutrients through leaching, liming of acid soils, decreased proportion of farm yard manure to chemical fertilizers, increased purity of high analysis fertilizers and use of marginal land of crop productions. Each essential elements can only perform its role in plant nutrition properly if other necessary elements are available in balanced ratios for plants. The increase of edible oils and oilseeds are increasing year after year to fulfil the increasing demand of Bangladesh. Appropriate policy measures are needed to increase oilseed production.

Bangladesh is not sufficient in oil production. But its population is huge. So, we have to depend on the international market to meet 90 per cent of our edible oil demand. In spite of increasing oilseed production Bangladesh produces only a small quantity of oilseeds. Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops and it is widely cultivated all over the world (Flagella *et al.*, 2002; Gonza´lez-Martı´n *et al.*, 2013). It has a huge probability to meet the demand of edible oil of our country. It grows well on neutral to alkaline soil with pH range of 6.5-8.0. Sunflower cannot grow well in acidic condition (Weiss, 1983). Because of its high adaptation capacity and relatively higher amount seed oil (40-50%) it is considered as one of the most important oilseed crops (Scheiner *et al*., 2002). In 2018-19, Bangladesh produced about 1975 metric tons' sunflower from 3187 acres' land (BBS, 2020). Sunflower has low cholesterol, that's why it has high demand. Sunflower oil is also good for health (Khatun *et al*., 2016). In 2008, 14 tons sunflower seeds oil was consumed. The crop has the potential to yield at least 1,000 kg ha^{-1} of seeds under rainfed conditions. Under assured rainfall situations, these can be increased up to at least 1,500 kg ha^{-1}. With rapidly increasing population, improved living standard and purchasing power of the people, the demand of vegetable oil in the country is increasing at the rate of 4 to 6% (Agarwal, 2008).

Lack of micronutrients causes decrease in chlorophyll density and yield on sunflower. On sunflower, corn, wheat and barley absence of Fe, S, Mg and Mn decreased the chlorophyll density in leaf and yield (Masoni *et al.,*1996). Foliar application of fertilizers and the respective fertilizer's soil application increase both crop quality and production (Memon *et al.,* 2003). Particularly the nutrients magnesium and sulfur are applied as foliar fertilizer in the form of Epsom salt very largely. Foliar application may be used to supply Boron (B) to a crop when boron demands are higher than can be supplied via soil. While boron foliar sprays have been used to correct B deficiency in sunflower in the field. Sunflower is one of the most sensitive crops to low boron supply. Sunflower develops characteristics of B deficiency symptoms on leaves, stems and reproductive parts (Blamey *et al*, 1979, 1987; Bergman, 1986; Asad *et al.*, 2002). In sunflower production, Boron deficiency also causes deformation of heads prior to and during the flowering stage (Blamey, 1976). Boron also has a role in some metabolic pathways like sugar transfer, respiration, carbohydrate, RNA, IAA, and phenol metabolism (Asad *et al.*, 2003).

Manganese is an important micronutrient for plant growth and development and sustains metabolic roles within different plant cell compartments. Manganese generally applied on plants in form of Manganese sulfate. Manganese sulphate fertilizer can be one of the beneficial organic amendments for the soil to ensure that plants are getting sufficient manganese. It plays an important role in plant growth and it can be applied both to the soil and as a foliar spray to correct any deficiencies. Foliar spray with boron and manganese became more important for oilseed crops such as rape and sugar beets. It helps to understand the reaction on visible deficiency symptoms within the fields (Shorrocks, 1997).

Zinc is also important for sunflower production. It is reported that enough zinc usage in alfalfa has basic role in both logging and water stress condition. Positive effects of foliar application of zinc were reported on sunflower (Sepehr *et al*., 2002). Enough zinc usage in alfalfa plant gives it protection from both water stress condition and water logging (Grewal and Wiliams, 2000).

There are three sunflower varieties are present in our country. They are BARI Surjamukhi-2, Surjamukhi-3 and Kirani DS-1. Due to severe loss of micronutrients like B, Mn and Zn in the soil we must need to add supplements of micronutrients to the soil. Therefore, in this study we will supplement B, Mn and Zn with recommended dose of fertilizers for sunflower production by soil and foliar feeding methods to evaluate the physiological growth, yield contributing characteristics, yield, oil content and quality of oil.

The present study was taken to several objectives.

1. To identify the application methods of micronutrient of sunflower.
2. To evaluate the effect of supplemented micronutrients on sunflower.
3. To evaluate the agronomical, physiological traits and oil content of sunflower as affected by micronutrient.

CHAPTER II

REVIEW OF LITERATURE

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops all over the world. Helianthus originates from the world 'Helios' meaning sun and 'Anthos' meaning flower. Sunflower is considered to be an efficient user of radiation energy because of its high phototropic nature and comparative superiority to other oil seed crops in terms of oil composition and yield. Sunflower seed contain 42-45% oil. Among the vegetable oils, sunflower oil is considered as most suitable for human consumption. Sunflower seed contains high level of linoleic and (64%) oleic acid (30%). Linolenic acid is not present in sunflower oil. Linoleic and oleic- unsaturated fatty acids constitute about 90% of the total fatty acids in its oils. The oil of sunflower is light yellow in color and possesses good odor which can be used for a variety of cooking purposes like any other edible oil. Sunflower oil is also used in the manufacture of soaps and cosmetics. The oil cake contains 40-44% high quality protein. It can also be used for manufacturing baby food. The sunflower kernels can be eaten raw or roasted.

2.1 Importance of sunflower as oilseed crop

Sunflower (*Helianthus annuus*) is a major source of high-quality edible oil. It is used as culinary purposes also (Pal *et al.*, 2015). Sunflower is native to North America. Nowadays It is cultivated throughout the world. Most of its products have been commercialized as culinary or livestock feed (Yegorov *et al*., 2019).

Based on its nutritional and medicinal value sunflowers importance is well known. sunflower has been recognized as functional foods or nutraceutical due to its beneficial health effects. The health benefits of sunflower include blood pressure and diabetic control, skin protection, and lowering cholesterol and other functions.

Sunflower is grown throughout the world as a source of premium oil and dietary fiber. These sources contribute to human health significantly (Khan *et al.*, 2015).

2.2 Origin and distribution of sunflower

Sunflower is a native of southern USA and Mexico. Before the middle of sixteenth century from USA and Mexico it was taken to Spain. In the nineteenth century, cultivation of sunflower as an oilseed crop began in former USSR and the majority of present-day varieties grown all over the world trace back their origin to the USSR. (Heifer *et al.,* 1969)

Global seed production of sunflower grows steadily in the last 25 years. Major producing countries are Ukraine, Russia, European Union and Argentina. Ukraine and Russia produce almost half of the world sunflower seeds. The total production of sunflower is approximately 45 million metric tons. The area under its cultivation was 26 million hectares in the world.

2.3 Climate and soil for sunflower production

Sunflower can be grown on a variety of soils ranging from sandy loams to heavy clay soils. It cannot tolerate waterlogging condition. Neutral to moderately alkaline soil is suitable for sunflower cultivation. For better growth of sunflower fertile soil, moderate rainfall, viable seeds etc. are essential requirements (Pal *et al.,* 2015).

Low soil ph. and high concentration of Alkali resulted in a significant reduction in sunflower growth and yield (Sutradhar *et al.,* 2014). Sunflower grows well on neutral to moderately alkaline soils with a ph. range of 6.5-8.0. It cannot tolerate acidic condition.

2.4 Sunflower cultivation in Bangladesh

In the tropics the crop grows best at medium to high elevations but can grow in low lands provided the same are not wet. In Bangladesh sunflower grows best in rabi season when land is usually dry. 12 hours day light is good enough for optimum growth of the plant. The favorable temperature is 20°–25℃. High temperature during seed development may reduce the oil content and the presence of linoleic acid. Farmers across Bangladesh are more inclined than ever to cultivate sunflowers as an alternative to traditional paddy crops that do not offer much profit. Bangladesh has to depend on the international market to meet 90 per cent of its edible oil demand as the country produces only a small quantity of oilseeds (The Daily Star).

Acute shortage of edible oil has been prevailing in Bangladesh during the last several decades. This shortage inherited from the past has been met through imports, using a huge amount of foreign exchange every year. Bangladesh produces 0.358 million tons of edible oil against the annual demand of 1.6 million tons. The remaining 1.242 million tons of the country's domestic requirements is met through imports (Hossain, 2014). The value of imported edible oils was Tk. 1, 38,141 million in 2014, (BB, 2014). Besides, the area under oilseeds cultivation is decreasing over the years due to various economic and technical reasons (Miah *et al*., 2014). The present total area under sunflower and other minor oilseed cultivation is 351.82 ha with a production of 373 metric tons in 2012 (BBS, 2012)

In Bangladesh, the demand of edible oil per year is 51.27 lakh metric ton. We need to import 46.21 lakh ton edible oil from different foreign countries every year. Recently, the scientists of our country had become interested to produce sunflower to fulfill the domestic oil demand. Besides its essential elements, it does not have harmful substance like uracil acid.

2.5 The role of micronutrients

C, H, O, N, P, K, Ca, Mg, S, Fe, Cu, B, Mn, Zn, Cl are essential elements for plant. Out of these 16 elements, 9 essential elements have been classified as macronutrients. These macronutrients are required relatively large amount by the plants. These elements include C, H, O, N, P, K, Ca, Mg, S. The remaining of the elements (B, Cu, Fe, Mn, Mo, Cl and Zn) are called trace elements (Alloway, 1990; Brady & Weil, 2002). These trace elements are also called micronutrients. they are required in relatively small amount in plants but in critical concentrations by living organisms.

The mineral elements like Zn, Fe and Cu are very crucial for human health. Micronutrients have significance as like as organic compounds such as carbohydrates, fats, protein and vitamins. The daily dietary intake of young adult ranges from 10-60 mg for Fe, 2-3 mg for Cu and 15 mg for Zn. Intake less than these values can cause slow physiological processes. These micronutrients deficiencies in soil are not only hampering the crop productivity but also are deteriorating produce quality. High consumption of cereal-based foods with low contents of micronutrients is causing health hazards in humans also (Imtiaz *et al*., 2010). Role of micronutrients is important both for human and plant.

2.6 Influence of micronutrients on oilseed crops

In oilseed crops micronutrients play a major role in translocation of photosynthates, increasing seed setting percentage. It is also essential for translocation of sugar, germination of pollen grains, stigma receptivity, amino acid and protein synthesis which ultimately increase the productivity of oilseed crops (Arabhanvi *et al.,* 2015).

The introduction of high yielding varieties, increasing cropping intensity, use of high analysis fertilizers and limited use of organic manures are causing the problem of micronutrient deficiency. (Singh *et al.,* 2010). These are causes for poor production of oilseed crops.

2.7 Influence of foliar micronutrient application on oilseed crop

Arabhanvi *et al*. (2015) suggested from previous studies that, application of micronutrients through foliar spray was found more beneficial than the soil application for oilseed crops. Application of micronutrients also leads to higher yield, uptake of nutrients and oil content in oilseed crops.

Foliar application of nutrients has become an efficient way to increase yield and quality of crops (Romemheld and El-Fouly, 1999; Savithri *et al.,* 1999). Foliar application of micronutrients can improve nutrient utilization and reduced environmental pollution by reducing the need of chemical fertilizer application in soils (Abou El-Nour, 2002).

Besides crop production foliar micronutrient application have beneficial effects on human and livestock health (Malakouti and Tehrani, 1999; Sharma *et al*., 1992).

In arid and semiarid regions where there is a scarcity of water, foliar application of nutrients is a more suitable option compared with soil fertilization. Because in those areas the roots cannot provide necessary nutrients from the soil. Other advantages of foliar application of micronutrients are quick compensation of nutrient deficiency, application of lesser rates. It also reduces toxicity arises from excessive accumulation of elements and preventing nutrients fixation in the soil (Malakouti and Tehrani, 1999).

There is an indication of positive influence of micronutrient application in increase of yield and quantitative parameters of crops (Tavassoli *et al*., 2010; Nagaraj, 1987; Mosavi *et al.*, 2007; Paygozar *et al*., 2009). Foliar application of micronutrients (iron and zinc) in various growth stages of sunflower had significant positive effect on 1000-seed weight, plant height, biological yield, grain yield, harvest index and oil content (Babaeian *et al.*, 2011).

Research results of Rashid *et al*. (1994) and Prasad and Prasad (1994) reported that with foliar spraying of copper and zinc, the yield, oil and protein content of rape seeds increased significantly. In micronutrient deficiency condition, use of micronutrients on shoots leads to increasing quality and quantity of safflower (Movahedi-Dehnavi *et al*., 2009 and (Lewis and McFarlane, 1986).

Safflower plants sprayed with B, Fe, Zn and a combination of B+ Zn showed significant increase of grain yield. The most seed yield was achieved from spraying with B micronutrient among these treatments (Sangale *et al*., 1981).

Manganese significantly increased seed yield of safflower through the increase of number of seeds per plant (Lewis and McFarlane, 1986). Besides that, the foliar and soil application of zinc and sulfur along with nitrogen and phosphorus fertilizers significantly increased grain yield, protein and oil content of safflower (Babhulkar *et al*., 2000).

Zinc (Zn) and manganese (Mn) are important micronutrients in oilseed crops like sesame production. Reduced growth hormone production in Zn deficient plants causes shortening of internodes and short leaves resulting in malformation of fruit with little or no yield (Seervi *et al*., 2018).

2.8 Influence of Boron in sunflower

Boron is a micronutrient element requiring for plant growth relatively to a smaller amount (Gupta, 1979). Deficiency of boron causes deformation of head prior to and during the flowering (Blamey, 1976). Boron is also essential for sugar translocation. Sugar translocation is very important because it affects the carbon and nitrogen metabolism of plants (Jackson and Chapman, 1975).

Foliar application may be used to supply boron to a crop when boron demands are higher than can be supplied via the soil. To correct B deficiency in sunflower (*Helianthus annuus* L.) in the field, B foliar applications have been used (Asad *et al*., 2003).

In dicotyledonous plants, the internal boron (B) requirement is generally higher than that of monocotyledonous plants both during vegetative and reproductive growth (Gupta, 1993).

B deficiencies occur over a much wider range of soils and crops in comparison to deficiencies of any other micronutrient elements (Yan *et al.*, 2006).

Boron is a very crucial micronutrient elements for plants. It is involved in the carbohydrate transportation within the plant, which helps in translocation of sugar and DNA synthesis in meristems. Boron plays a vital role in many important factors in plant physiology such as cellular differentiation and development, nitrogen metabolism, fertilization, active salt absorption, hormone metabolism, water relations, fat metabolism, phosphorus metabolism and photosynthesis (Seervi *et al.,* 2018).

A previous experiment showed, in oilseed crop soil application of boron @ 1.5 kg ha^{-1} recorded significantly higher plant height and more branches compared to control (Nandini *et al*., 2012).

Boron deficiency decreased the dry matter yield of oilseed plants (Sharma and Ramchandra, 1990). Boron deficiencies occur over a much wider range of soils and crops in comparison to deficiencies of any other micronutrient elements (Yan *et al.*, 2006).

Application of B @ 1 kg ha^{-1} increased leaf area ratio (LAR), Leaf area Index (LAI), crop growth rate, number of branches $plant^{-1}$, number of pods, plant weight, seeds $head^{-1}$ and a decrease in chlorophyll content and net assimilation rate. But relative growth rate, total dry matter and seed yield and some other growth attributes were unaffected. (Dutta *et al.*, 1984). A previous experiment showed that, the critical B concentration in the youngest opened leaf (YOL) of sunflower plants was 20 mg kg^{-1} at 10 DAT (Asad *et al.*, 2000).

Both canola and sunflower are more sensitive than many other crops to low B supply. Yield loss of canola and sunflower loss due to boron deficiency has been reported from around the world (Bell *et al*., 1990; Blamey *et al.*, 1997; Liu et al., 1981; Takkar *et al.*, 1989).

In canola and sunflower low B supply in a growth medium result in poor growth and seed set (Asad *et al.*, 1997b; Blamey *et al.*, 1997).

In sunflower boron deficiency symptoms first become evident on the younger leaf blades. Because of boron deficiency, sunflower plant develops a bronze color and become hardened, malformed and necrotic (Blamey *et al.*, 1997). Not just the leaf and branches, sunflower roots are also sensitive to B deficiency as they stop their growth in < 6 h after the removal of B from the growth medium (Dugger, 1983).

During the late vegetative or early stage in canola and sunflower plant it has been observed that B deficiency symptoms often become evident or become more severe (Asad *et al.*, 2000; Gupta, 1993; Blamey *et al.*, 1997). The reason for this has not been fully explained, but could be due to a decreased supply of B either by late season drought or depletion of B in soil or solution culture. Alternatively, there may be increased sensitivity to low B supply during reproductive development. (Hu *et al.*, 1996; Matoh, 1997). Foliar application of boric acid (H_3BO_3) in Alstar sunflower hybrid increased seed number per anthodium 6.55% more than control (Farzanian *et al.*, 2010).

Balanced boron nutrition is also indispensable for optimum crop growth, development and achene yield of sunflower (Goldbach *et al.*, 2001).

Boron is a necessary microelement which is more needed for natural growth of plants (Tisdale *et al.*, 1990). Oil and protein percentage of peanut increased by foliar application (Nadia *et al.*, 2006). Foliar application of boron relates to boron role in basic metabolic reactions and quicken the rate of protein synthesis. Boron also plays a role in plant metabolic pathways such as sugar transfer, respiration, carbohydrate, RNA, IAA, and phenol metabolism.

Foliar boron application by shortage time in sunflower is useful and increase boron in leaves (Asad *et al.*, 2003). The effect of boron on sunflower was observed and concluded that boron shortage decreases root and stem weight, leaf surface and chlorophyll amount (Kastori *et al.*, 1995). During this experiment photosynthesis decreased because of decreasing boron. Because of decrease of photosynthesis electron transfer and sugar transport in leaves also decreased.

Previous research experiments demonstrated that, seed yield and oil yield of sunflower were increased by B consumption. It also increased the pollen fertility with increase of the number of filled grain (Brighenti and Castro, 2008).

Sunflower has been found to be particularly sensitive to B deficiency and is sometimes used as an indicator for assessing available B in soils (Oyinlola, 2007). Depending upon the dose used as a fertilizer yield and the component in vegetative and reproductive

stages of sunflower may both be affected positively and negatively. In B deficient soils, foliar applied B significantly enhanced the vegetative and reproductive dry matter of plants. B application improved the total dry matter three times in B deficient plants than in B sufficient plants (Asad *et al*., 2003).

2.9 Influence of Manganese in sunflower

Manganese (Mn) is an important plant micronutrient and is required by plants in the second greatest quantity compared to iron. Manganese can have a limiting factor on plant growth if it is deficient or toxic in plant tissue. Although it is used in small amounts by plants, manganese is of capital importance to healthy plant growth, like all micronutrients. Among others, it plays a significant part in the process of photosynthesis.

The function of Mn at the cellular level of plant is to bind firmly to lamellae of chloroplast, possibly to the outer surface of thylakoid membranes, affecting the chloroplast structure and photosynthesis (Lidon and Teixeira, 2000).

Mn is required in both lower and high plants for the Hill reaction. It is mainly the water splitting and oxygen evolving system in photosynthesis. Photosystem II contains a manga noprotein which catalyzes the early stages of O_2 evolution. Exogenous application of manganese in adequate amount may result an increase in photosynthetic activity and growth rate of cells in barley under salinity (Cramer & Nowak, 1992).

Application of Manganese significantly increased seed yield of safflower through the increase of number of seeds per plant (Lewis and McFarlane, 1986).

Foliar application of minerals like iron, boron, manganese and copper may be more practical than application to the soil where they adsorbed to the soil particles. They are also less available to the rooting medium (Sarkar *et al.,* 2007; Wissuwa *et al.,* 2008). Two to three foliar applications may be all that are needed to meet crop demands.

Deficiencies of various micronutrients are related to soil types, crops and various cultivars. Most of the micronutrients like Fe and Mn are readily fixed in soil. They have alkaline Ph. Plant roots are unable to absorb these nutrients sufficiently from dry topsoil (Graham *et al.,*1992 and Foth and Ellis, 1996). The application of macro and micronutrients fertilizer in the cultivation zone may not be meeting the crop requirement for root growth and nutrient use. The alternative approach is to apply these micronutrients as foliar sprays.

2.10 Influence of Zinc on sunflower

Foliar application of Zn in 2.0% concentration can be employed to increase the sunflower yield and oil content. Previous study suggests that Zn can be employed for improving sunflower yields and quality, especially in Zn deficient regions (Keerio *et al.,* 2020).

Zinc deficiency is a worldwide nutritional constraint for plant growth, particularly in calcareous soils of arid and semi-arid regions. Through plant harvesting large amounts of zinc from the soil. little attention has been paid to fertilizing with Zn (Takkar and Walker, 1993). Zinc nutrition of crops is necessary because of its importance in maintaining the membrane integrity of root cells (Cakmak and Marschner, 1988; Welch *et al*., 1982). Zinc also has the possible role in reducing the toxic effects of boron (B) (Graham *et al.,* 1987;

Singh *et al.,* 1990), sodium (Na), and chloride (Cl) (Takkar and Walker, 1993).
Excessive B, Na, and Cl are not good for soil and crops and it's been a problem in a large proportion of the soils (Khoshgoftarmanesh *et al*., 2004).

Zinc fertilization is an agronomic practice widely used by farmers to correct Zn deficiency (Yilmaz *et al.*, 1997). Zinc deficiency in plants is most frequently corrected by application of Zn to soils (Yilmaz *et al.*, 1997). Zinc sulfate ($ZnSO_4$) is a common source of Zn fertilizer because of its high solubility in water and existence in both crystalline and granular forms (Mordvedt and Gilkes, 1993). Zinc deficiency in crop species is usually corrected by applying 4.5–34 kg Zn ha^{-1} in the form of $ZnSO_4$ (Martens and Westermann, 1991).
The amount of $ZnSO_4$ needed to correct Zn deficiency depends mainly on the severity of Zn deficiency in the plant and the levels of available Zn in soil (Yilmaz *et al.,* 1997).

The effects of Zn fertilization on growth and yield of many plants such as wheat (Triticum spp.) (Yilmaz *et al*., 1997; Khoshgoftarmanesh *et al*., 2004), rice (*Oryza sativa* L.) (Martens and Westermann, 1991), and alfalfa (*Medicago sativa* L.) (Grewal and Williams, 2000) have been investigated.

Zn fertilization had a positive effect on sunflower and increased its seed and straw yield. Concentration of seed oil of sunflower also elevated by the application of zinc (Khurana and Chatterjee, 2001). Sunflower is quite responsive to Zn deficiency which is prevalent on a wide range of soils in many countries of the world (Tiwari *et al.,* 2014).

Foliar spraying of copper and zinc significantly increased the yield of rapeseed and oil and protein content of the seeds (Rashid *et al.,* 1994; Prasad and Prasad, 1994).

As a fertilizer, zinc sulfate plays a major role in regulation of stomata influencing the photosynthesis and ionic balance in plants. Zinc is also involved in drought tolerance characteristic of plants (Babaeian *et al.,* 2010; Baybordi, 2006; Kassab, 2005).

Use of Zn along with other fertilizers can be adopted to overcome the obstacle the Zn deficiency on soil. Zn enhances the growth, plant height, leaves and dry matter production of sunflower. Such ameliorations in crop parameters can be attributed to improved metabolic role of this micronutrient (Torun, 2013).

Foliar fertilization is increasingly popular especially regarding production of high value crops such as sunflower (Fernández and Brown, 2013; Fernández *et al.*, 2013). Foliar application of Zn has been reported to produce positive response on seed yield and seed quality of sunflower (Jabeen *et al.*, 2013; Skarpa *et al.*, 2013; Yang *et al*., 2013; Tahir *et al.*, 2014).

Foliar application of Zn is also suggested to alleviate the adverse effects of water stress on plant photosynthesis and photosynthesis-related characteristics. It’s also playing a major role on yield contributing traits on oilseed crops (Kassab, 2005).

Zinc is essential for sugar regulation and enzymes in plants that control plant growth (Halvin *et al.*, 1999).

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental period and site

The field experiment was conducted at the Agronomy research field of Sher-e-Bangla Agricultural University (SAU), during the period of Rabi season from November, 2020 to March 2021 to evaluate the influence of soil and foliar applied micronutrients (B, Mn, Zn) for improving the physiological traits, yield components and oil content of sunflower. After finishing field experiment, laboratory experiment was also conducted at the Biochemistry lab of Sher-e-Bangla Agricultural University to extract oil from sunflower seed to evaluate the oil content percentage and protein.

3.2 Geographical location

The experimental site was located at 23° 41'N latitude and 90° 22' E longitude with an altitude of 8.6 meters above the sea level.

3.3 Agroecological Region

The experimental site belongs to the agroecological zone of "Madhupur Tract", AEZ-28 (Anon., 1988a). The experiment site is shown for better understanding in the AEZ of Bangladesh in appendix I. Madhupur tract was a region were soils developed over the Madhupur clay. There were small hillocks of red soils surrounded by floodplain (FAO-UNDP, 1988).

3.4. Climate and Soil

The field of the experimental site belongs to the Tejgaon series which was characterized by shallow red brown terrace soils. The soil was well drained and medium high. The soil was loam in texture and having soil pH ranges from 6 to 7. The physiochemical properties of the soil such as presence of pH, organic matter, total nitrogen, phosphorous, potassium, boron, manganese and zinc were chemically analyzed from Soil Resource Development Institute (SRDI), Farmgate, Dhaka. The data is shown on Table 1.

The experiment was conducted in the Agronomy research field during rabi season. The winter or dry season extends from November to February and the temperature was moderately low. Rainfall was also very low. During March to April the temperature rises with less rainfall. Information regarding monthly maximum and minimum temperature, rainfall, relative humidity and the sunshine hour of the experimental site was collected from Yearbook of Agricultural Statistics-2021 and presented in Appendix III.

Table 1. Chemical properties of experimental soil

Properties	Values	Critical limit
pH	6.7	5.5-8.0
Organic matter (%)	2.64	2
Total Nitrogen (%)	0.15	3
Boron (ppm)	3.96	25
Manganese (ppm)	83.26	> 400
Zinc (ppm)	28.56	19
Phosphorus (ppm)	22.60	1 mg/dL
Potassium (meq / 100 g soil)	0.18	0.2

Seeds are obtained from Bangladesh Agricultural Research Institute (BARI). At first before starting the experiment soil micronutrient and soil organic matter contents were measured in Soil Resources Development Institute (SRDI).

3.5 Planting materials

Only one variety of sunflower was used as a planting material. The variety is BARI Surjamukhi-2, which was collected from Bangladesh Agricultural Research Institute (BARI). This variety generally grown well in winter or Rabi season. So, in the last period of November seeds were directly sown in research plot.

3.6 Treatments and Factors of the experiment

There are 7 treatments used in this experiment. The micronutrient combinations were identified as ‘T’ and the micronutrient application methods were identified as ‘F’.

T_1= Boron

T_2= Manganese

T_3= Zinc

T_4= Boron + Manganese

T_5= Boron + Zinc

T_6= Manganese + Zinc

T_7= Boron + Manganese + Zinc

There are two methods applied in this experiment.

Factor A, F_1 = Soil Application

Factor B, F_2 = Foliar Application.

In the experimental plots micronutrients were applied, boron as boric acid (12 kg ha^{-1}), zinc as zinc sulphate (10 kg ha^{-1}) and manganese as manganese sulphate (12 kg ha^{-1}) as soil application. On the other hand, Zn (2 %), Mn (1%) and B (0.5%) was applied as foliar application. The recommended dose of N as Urea, P as TSP and K as MoP (180:150:120 kg ha^{-1}) were applied along with soil application and foliar application of micronutrient. Foliar treatment was applied in three splits at 30 DAS, 50 DAS and 70 DAS. All the treatments were applied by balancing to the initial soil test values and crop requirements to justify the crop response to the supplied nutrients.

3.7 Design and layout of the experiment

The experiment was laid down in Randomized Complete Block Design (RCBD) with three replications. Replication were done to keep error in a minimum rate. In each replication, there were 7 treatments and 2 factors, total (7×2) 14 plots. So, in 3 replications there were (14×3) = 42 plots. Size of each plot was 2.5 m^2. Plant to plant distance was 25 cm and row to row distance was 50 cm.

3.8 Description of factors

Recommended dose of micronutrients were applied in soil during final land preparation. Boron, manganese and zinc which are the selected specific micronutrients for the research were applied by foliar application in the selective plots. Foliar application was done in three splits at 30 DAS, 50 DAS and 70 DAS, during the total life period of sunflower. In this case, recommended dose of foliar micronutrients were not applied during final land preparation.

3.9 Land preparation and fertilizer dose

The experimental land was well prepared by ploughing with tractor and followed by laddering and cross laddering. All the debruises and uprooted weeds were removed from the field. All essential fertilizers were applied and mixed with soil properly before seed sowing in a required dose. Cow dungs were also applied and mixed properly during land preparation.

Table 2. Recommended Fertilizer application rate

Fertilizer	Kg ha^{-1}
Urea	200
TSP	180
MOP	170
Gypsum	170
Zinc Sulfate	10
Boric Acid	12
Manganese Sulfate	12
Cow dung	10 ton

Half of the Urea and full amount of the other fertilizers were applied at the time of final land ploughing and were mixed with soil by laddering and cross laddering. Rest half of the urea was applied in 2 splits. Urea was applied as topdressing, 1^{st} split was applied 20-25 days after emergence and the second one at 40-45 days after emergence.

3.10 Collection and sowing of seed

One kg of BARI Surjamukhi-2 seeds was collected from Bangladesh Agricultural Research Institute. Before sowing, the seeds were treated by seed treating chemical named vitavex 200. To protect the seed from soil and seed borne diseases 3 gm vitavex 200 fungicide was mixed in 1 kg seed. It was mixed to the whole seed properly.

3.11 Intercultural operations

All experimental plots were always kept under careful observation. After emergence of seedlings, the following intercultural operations were accomplished.

3.11.1 Thinning

After the emergence of sunflower seedlings, thinning was done several times. It was necessary to maintain the required number of sunflower plants in a specific plot. Thinning was done by hand. First thinning was done 10 days after seed sowing. Plant to plant distance was 25 cm and row to row distance was 50 cm.

3.11.2 Water Management

Water management or irrigation is a very important part for the growth and development of any crop. In sunflower plant irrigation needed for several times for better yield. First irrigation was done after the emergence of seedlings. Then another two times irrigation was done with 20 days interval.

3.11.3 Weeding

Sunflower crop is very sensitive to weed. During experiment, the plot was infested by weeds. Weeding was done two times during the experiment by hand pulling.

3.11.4 Earthing up

Earthing up is a very important interculture operation for crops. Earthing up was done 2 times. The first earthing up was done 20 days after seed sowing and the second one was done 30 days interval.

3.11.5 Gap filling

Gap filling of sunflower plant was also done when one or two sunflower seedling was not grown in a plot. To maintain the similarity gap filling was needed. Gap filling was done manually from the border plants.

3.12 Plant protection measures

During the entire course of crop production, plant protection measures were taken regularly. There was an infestation of reddish-brown caterpillar in the research field, Marshal 20 EC was applied. To control Alternaria disease, Rovral 50 WP was used several times @ 2% mixed with water. Sunflower plant faces wilting during the experiment. To solve the problem Austin was applied. Red pumpkin beetle was also attacked the plant. To prevent this problem, insecticide Aktara was applied according to required doses.

3.13 General observation

The field was observed frequently and regularly to notice and check any kind of changes in plant characters, soil condition, soil moistures. Attack of insects or funguses also checked and proper protection measure was taken.

3.14 Harvesting and Threshing

All the crops were harvested in a same date. On March 10, 2021, harvesting was done. After harvesting the seeds were sun dried in open space to reduce the moisture to avoid fungicidal attack. On this period proper inspection and protection was taken before threshing. Threshing of sunflower seed was done by hand.

3.15 Sampling and processing of the data

There was total 42 plots in the experiment. In each plot there were 3 rows and 18 plants. From the middle row of each plot 3 plant was selected for data collection. Agronomic data was taken during the field experiment. Yield contributing data were taken after harvesting.

3.16 Parameter measurement and data recording

3.16.1 Plant height (cm)

Plant height of the selected plants from each plot has been measured 3 times 20 days interval starting from 25 DAS. Height was measured from the ground level. By long ruler the height was measured.

3.16.2 Leaf number Plant^{-1}

Total number of leaves from the selected plant for data collection was measured by hand. 3 times number of leaf was measured and average was done.

3.16.3 Leaf area index

Leaf area index is a very important parameter to identify the agronomic growth of a crop. To identify leaf area index, at first leaf area and no of leaf of the plant was measured. It was measured considered to 1 m^2 area. The following formula was used to measure LAI.

LAI= (Leaf area × No of leaf × No of plant) / 1 m^2

Leaf area of sunflower was measured from the selected plant from each plot. To measure the leaf area, 3rd leaf from the upward was selected. Leaf area was measured three times to minimize the error level.

3.16.4 Total dry matter

To calculate dry matter content 2 plants from every single plot was collected randomly. Its fresh weight was measured through electric weight balance. After measuring fresh weight, the whole plant was oven dried in laboratory for undisturbed 72 hours. Then dry weight of whole plant measured.

3.16.5 Crop growth rate

Crop growth rate is a simple and important index of agricultural productivity (Hunts, 1978). The CRG value had been computed 2 times. Dry weight of a crop is needed in 2 different intervals to calculate this value. The formula is given bellow.

$CGR= (W_2-W_1)/(T_2-T_1) \times 1/A$

Here,

W_1= Total dry matter at time T_1.

W_2= Total dry matter at time T_2.

T_1= The period of previous observation

T_2= The period of final observation.

3.16.6 Relative growth rate

Relative growth rate is the rate of dry matter increase in per unit of total dry matter (TDM) per unit of time. RGR was calculated through 2 successive dry weight of the whole plant. Mathematical formula ln is used to determine the parameter. The equation given bellow.

$RGR\ (gg^{-1}day^{-1}) = (\ln W_2-\ln W_1)/\ (T_2-T_1)$

Here,

ln= Logarithm at base

W_1= Total dry weight at time T_1

W_2= Total dry weight at time T_2

T_1= The time period of previous observation

T_2= The time period of final observation.

3.16.7 Chlorophyll content

Chlorophyll is the pigment that gives plants their characteristic green color. In the physiology, productivity and economy of green plants chlorophyll content plays a huge role (Palta,1990). The chlorophyll content of sunflower plant was measured by SPAD meter three times during the course of the research. The second uppermost fully expanded three leaves were randomly selected from each plot. The top and bottom of each leaf were measured with SPAD and then it was averaged.

3.16.8 Relative water content

Relative water content (RWC) was measured at different time span during the growth of sunflower. To determine RWC, leaves were randomly selected from each plot and cut with scissors. Fresh weight (FW) of leaf laminas was weighed by using electric balance. Then placed immediately between two layers of filter paper and submerged in distilled water in a Petri dish for 24 h in a dark room. Turgid weight (TW) was measured after gently removing excess water with a paper towel and then dried 72 h at 70°C in a drying oven and re-weighed for determining dry weight (DW). Leaf RWC was estimated by using the following formula-

$$RWC (\%) = (FW-DW)/ (TW-DW) \times 100$$

Here,

FW= Fresh weight of single leaf.

DW= Dry weight of single leaf.

TW= Turgor weight of single leaf.

3.17 Yield contributing characters

Head diameter, thousand seed weight, Number of seeds head^{-1}, seed yield, biological yield, stover yield, harvest index was measured properly. Head diameter was measured by scale. Thousand-gram seed weight, number of seeds were measured manually. Yield data were measured by electric balance.

Seed yield was measured from the previously selected plants from each plot. All the seeds weight from a single head was measured through electric balance. Stover yield was measured. To calculate stover yield without the seed of a plant, rest of the weight was measured.

Harvest index is the parameter which gives us the indication of how much grain yield or economic production of a plant happened according to total plant. It denotes the ratio of economic yield to biological yield. For measuring harvest yield, biological yield and seed yield have to measured. The following formula was given by Donald (1963).

Harvest Index (%) = (Grain yield/ Biological yield) × 100%

3.18 Seed moisture percentage

To calculate seed moisture percentage, at first fresh weight of seeds were measured, then the oven dry weight was measured. The difference between the fresh weight and oven dry weight was calculated to measure seed moisture (%).

3.19 Oil content

The sunflower oil was extracted using Soxhlet method (Aziz *et al.*, 2018) with some modifications. Sunflower seeds were mashed properly by using a blender. Then sample was taken into 25x100 mm cellulose Soxhlet extraction thimble (Whatman 2800-250). (Sumon *et al.,* 2020). Oil percentage was measured through the following formula-

Oil percentage of seeds= Weight of extracted oil/ Weight of seeds × 100.

3.20 Protein percentage

The protein content of sunflower seed was obtained by determining the nitrogen content of the sample. Then the nitrogen content was multiplied by the protein factor 6.25 (Earle *et al*., 1968). The Kjeldhal method (AOAC, 2010) was used to estimate nitrogen content.

3.21 Statistical analysis of data

The recorded data for all the agronomic, physiological, yield contributing and oil content parameter was tabulated in a proper form for statistical analysis. The collected data was measured by computer-based program STATISTIX-10. The mean differences among the treatments were adjudged by Least Significant Difference (LSD) (Gomez and Gomez, 1984). Pairwise comparison, treatment combination, treatment and factor comparison alone were also done by this software. Mean separation was done by LSD AT 5% level of significance to avoid error percentage.

CHAPTER IV

RESULTS AND DISCUSSIONS

The present study was conducted to evaluate the influence of micronutrients (Boron, Manganese, zinc) on growth, physiological traits, yield and oil quality of sunflower. The treatment interaction with the micronutrient application method was observed. The results obtained from the field and lab experiment have been presented, discussed and compared in this chapter through tables and figures. The analysis of variances (ANOVA) of the data of different parameters are given in Appendix section. The analytical results of the experiment have discussed through necessary tables and figures. The present experimental findings were compared with the previous similar research works.

4.1 Effect of different micronutrients treatment and application method on different parameters of sunflower

4.1.1 Plant height

The effect of different micronutrient combination significantly differed for plant height of sunflower at different growth stages (Figure 1). Plant height due to different treatment combination ranged from 20.46 to 25.53 cm in 25 DAS, 56.48 to 82.66 cm in 45 DAS and 112.35 to 144.76 cm in 65 DAS. Plant height increased progressively up to maturity stage regardless of treatment combination. The treatment combination of boron, manganese and zinc (T_7) showed the highest plant height which was similar to T_5 and T_6. at all the growth stages. The results are in agreement with those of Faisal *et al.* (2020) who reported that the solo application of boron @ 0.7% gave the maximum plant height (138.93 cm).

Plant height was not significantly affected by the application method of micronutrients at all the growth stages of sunflower except 65 DAS (Figure 2). Foliar application (F_2) showed higher plant height (22.65 cm) than the soil application (F_1) (22.22 cm) at 25 DAS. At 45 DAS foliar application (F_2) showed higher plant height (73.83 cm) and the soil application (F_1) gave the lower plant height (67.29 cm). Similarly at 65 DAS foliar application (F_2) gave higher plant height (134.02 cm) than soil application (126.09 cm)

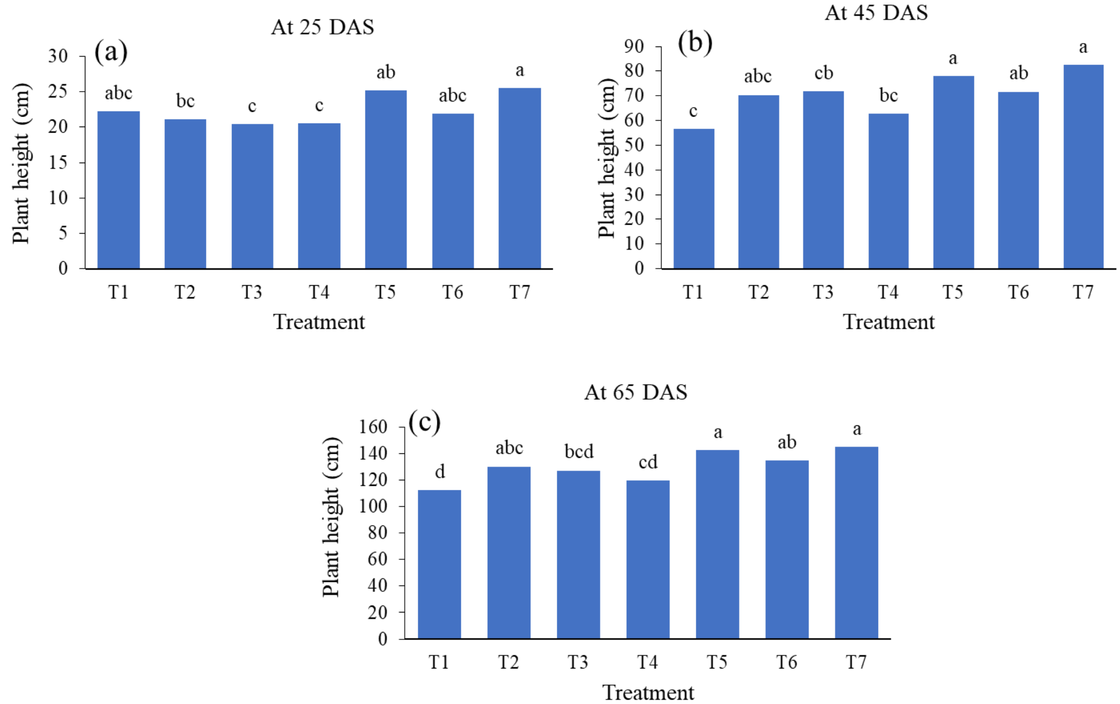

Figure 1. Effect of different micronutrients on plant height at different days after sowing (DAS) of sunflower. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

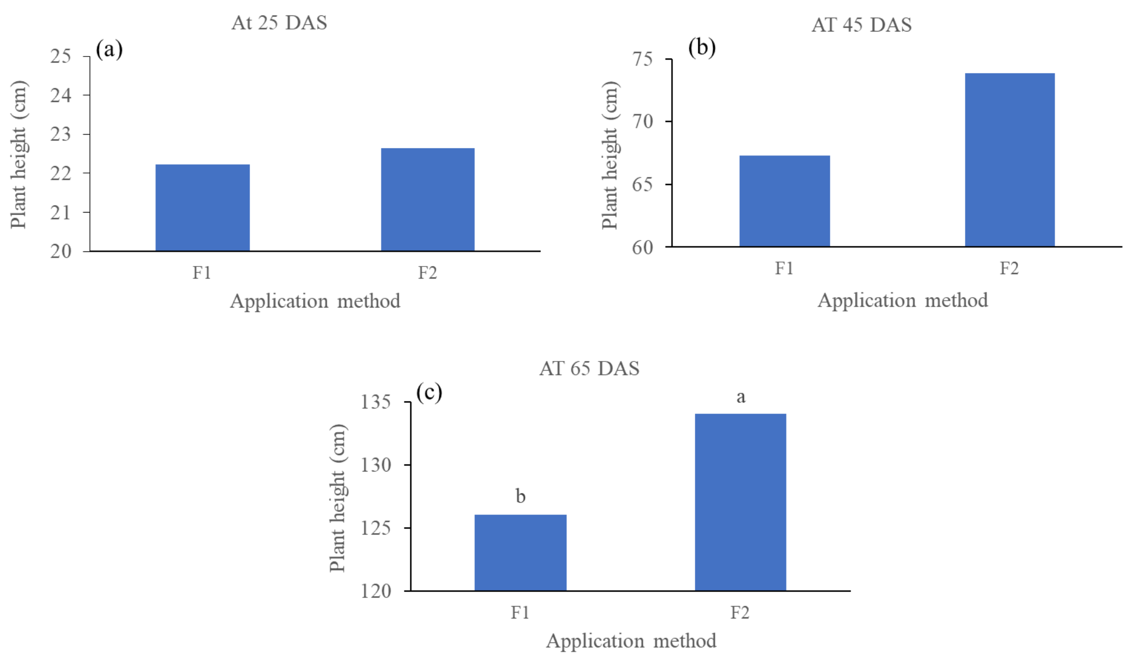

Figure 2. Effect of micronutrient application methods on plant height at different days after sowing (DAS) of sunflower. [Here, F_1= Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.2 Number of leaf plant^{-1}

Significant variation in leaf number plant^{-1} was observed by applying different combinations of micronutrient treatment at all growth stages (Figure 3). At 25 DAS maximum leaf plant^{-1} (6.83) was obtained from the treatment combination of boron, manganese and zinc (T_7) and the minimum leaf count (5.83) obtained from the solo application of boron (T_1). The treatment combination of boron, manganese and zinc (T_7) also showed the best performance at 45 DAS (16) and 65 DAS (19.33). The lowest leaf number found from the solo application of manganese (T_2) both at 45 DAS (12.5) and 65 DAS (16.67). The leaf number plant^{-1} was increased progressively during the growth stages until reached the maturity stage. There was no such significant difference observed on leaf number due to different application methods (Figure 4). At 25 DAS (6.38) and 45 DAS (14.48) numerically higher leaf number was found from the foliar application of micronutrients (F_2). But at 65 DAS numerically better leaf number (18.09) was obtained from soil application of micronutrient (F_1).

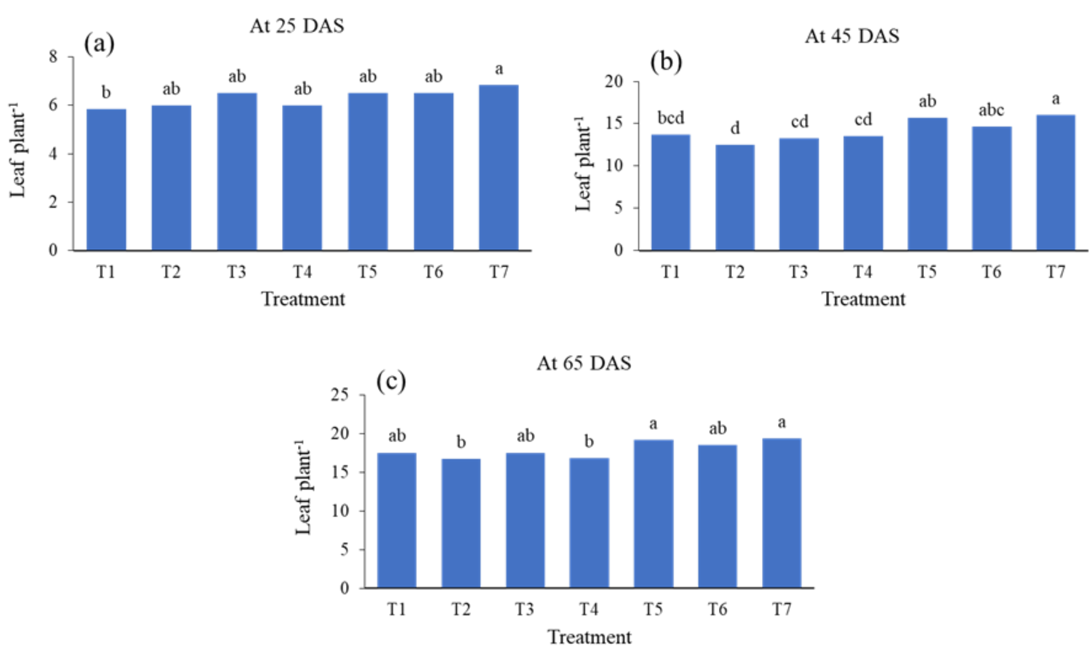

Figure 3. Effect of different micronutrients on leaf plant^{-1} at different days after sowing (DAS) of sunflower. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

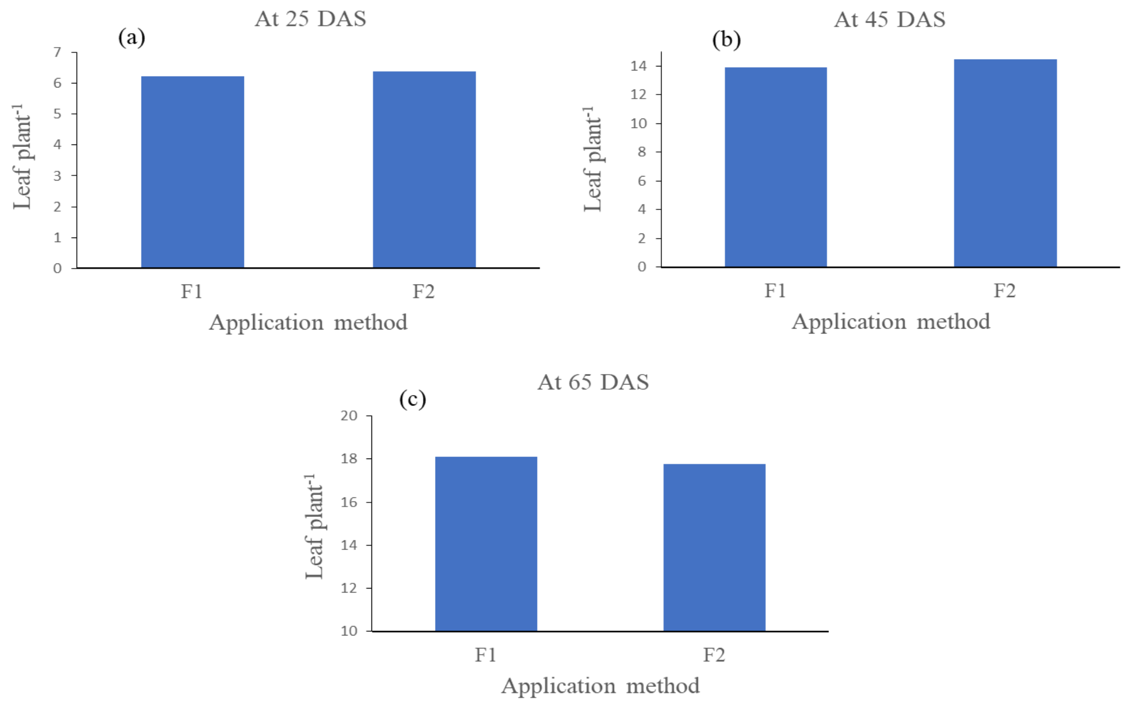

Figure 4. Effect of micronutrient application methods on leaf plant^{-1} at different days after sowing (DAS) of sunflower. (a) 25 DAS, (b) 45 DAS (c) 65 DAS. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.3 Leaf area index

Leaf area index (LAI) of sunflower plant was affected significantly at the growth stages due to different levels of treatment combination (Figure 5). LAI was significantly affected by treatments at 25 DAS, 45 DAS and 65 DAS. At 25 DAS, highest LAI (0.20) was observed from the treatment combination of boron, manganese and zinc (T_7) which was similar to T_3, T_5 and T_6 but higher than T_1 and T_4. At 45 DAS (2.14) and 65 DAS (3.19) the maximum LAI was found from the treatment combination of boron and zinc (T_5) respectively. It was revealed that, regardless of treatment differences, leaf area index increased progressively until maturity stage. Meanwhile lowest LAI was obtained from the solo application of boron (T_1) at 25 (0.10) and 45 DAS (0.87). At 65 DAS minimum LAI was found from the combined application of boron and manganese (T_4).

There was no significant effect of application method of micronutrients at all the growth stages. (Figure 6). Leaf area index increased with age reaching peak at 65 DAS. At 45

DAS (1.70) and 65 DAS (2.61) numerically higher LAI was found from the foliar application of micronutrient (F_2) and at 25 DAS numerically higher LAI value (0.14) was obtained from the soil application of micronutrient (F_1). But there was no statistical difference between these two application methods.

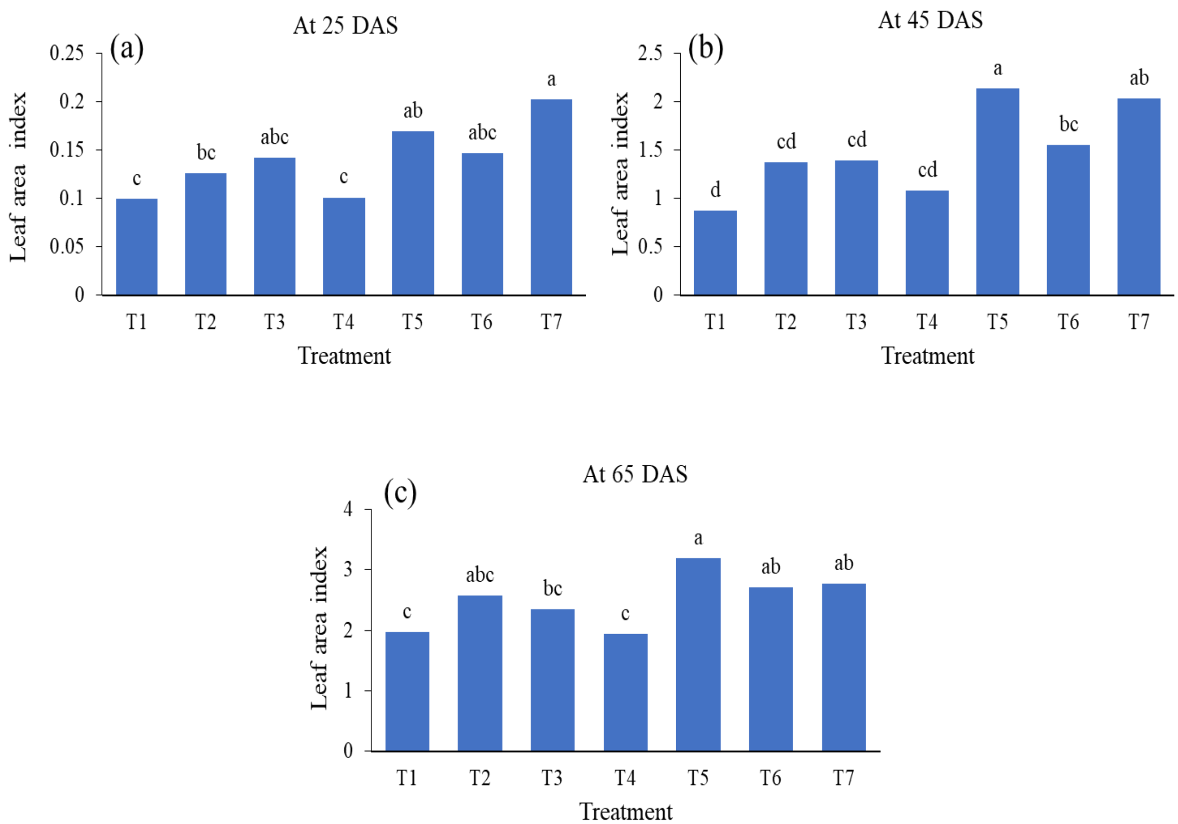

Figure 5. Effect of different micronutrients on leaf area index at different days after sowing (DAS) of sunflower. (a) 25 DAS, (b) 45 DAS (c) 65 DAS. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

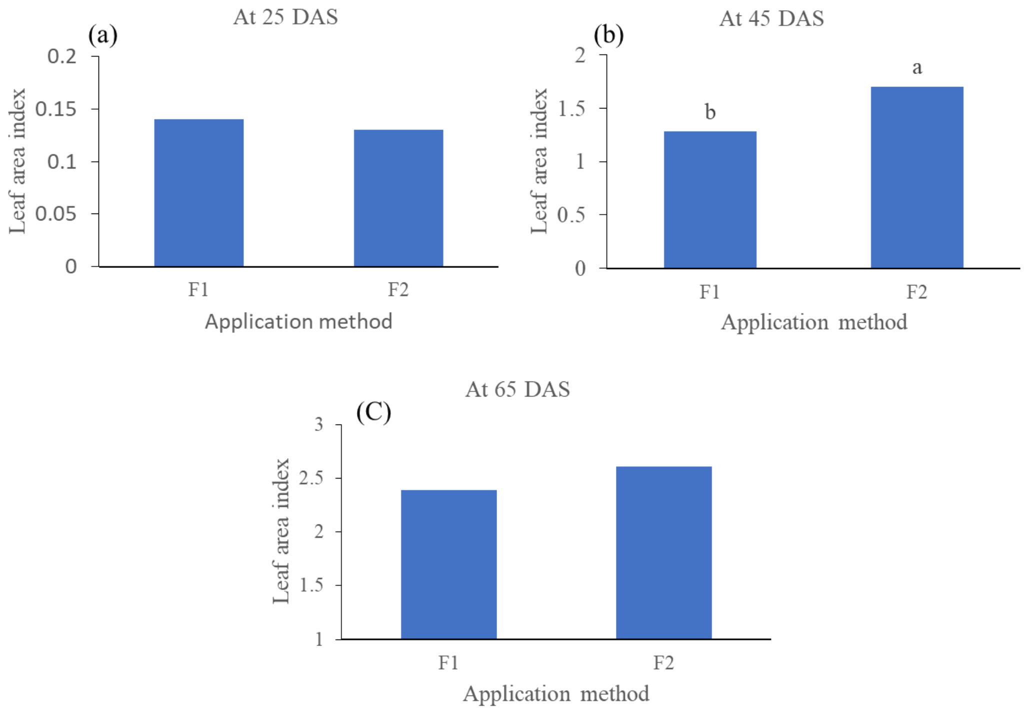

Figure 6. Effect of micronutrient application methods on leaf area index at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.4 SPAD Value

The effect of micronutrient combination was significantly differed for SPAD value of sunflower at different growth stages (Figure 7). Combined application of boron, manganese and zinc (T_7) significantly influenced the SPAD value at 45 DAS and 65 DAS. At 45 DAS (40.6) and 65 DAS (38.79) highest SPAD value was observed from the combined application of boron, manganese and zinc (T_7). At 25 DAS maximum SPAD value (39.03) resulted from the treatment combination of manganese and zinc (T_6). Numerically higher SPAD value found from 45 DAS. There was no significant effect of micronutrient application method at different growth stages of sunflower plant on SPAD value (Figure 8). There was no statistical difference between these two application methods. But at every growth stage the soil application of micronutrient (F_1) showed numerically higher SPAD value than foliar application of micronutrients (F_2). At 25 DAS (37.19), 45 DAS (38.13) and 65 DAS (38.04) numerically higher SPAD value was resulted from soil application of micronutrients (F_1).

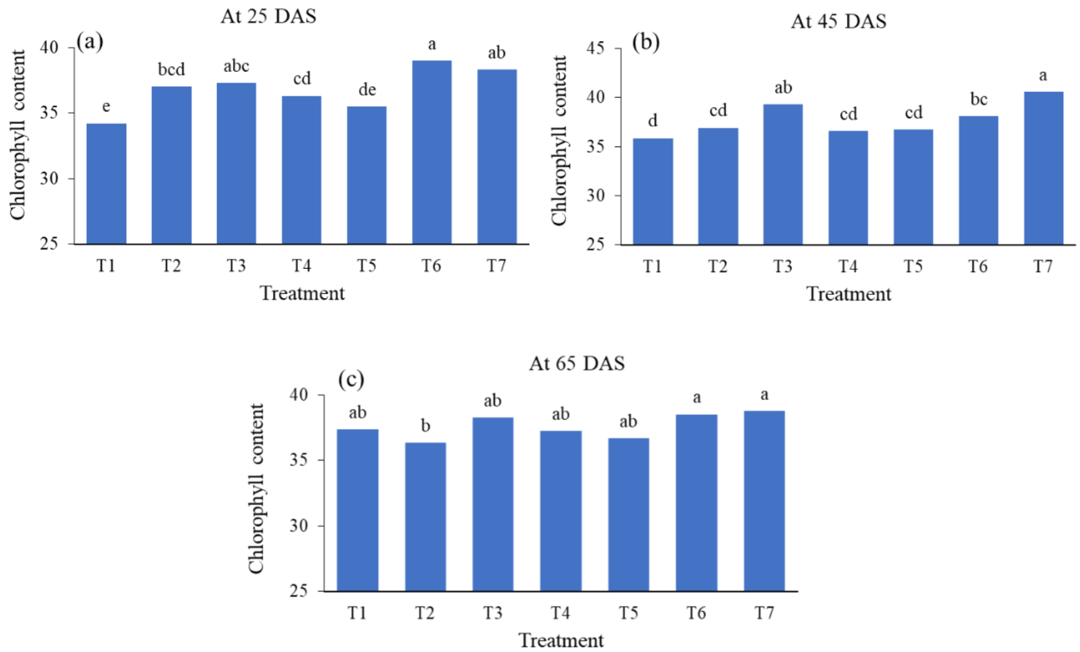

Figure 7. Effect of different micronutrients on chlorophyll content at different days after sowing (DAS) of sunflower. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

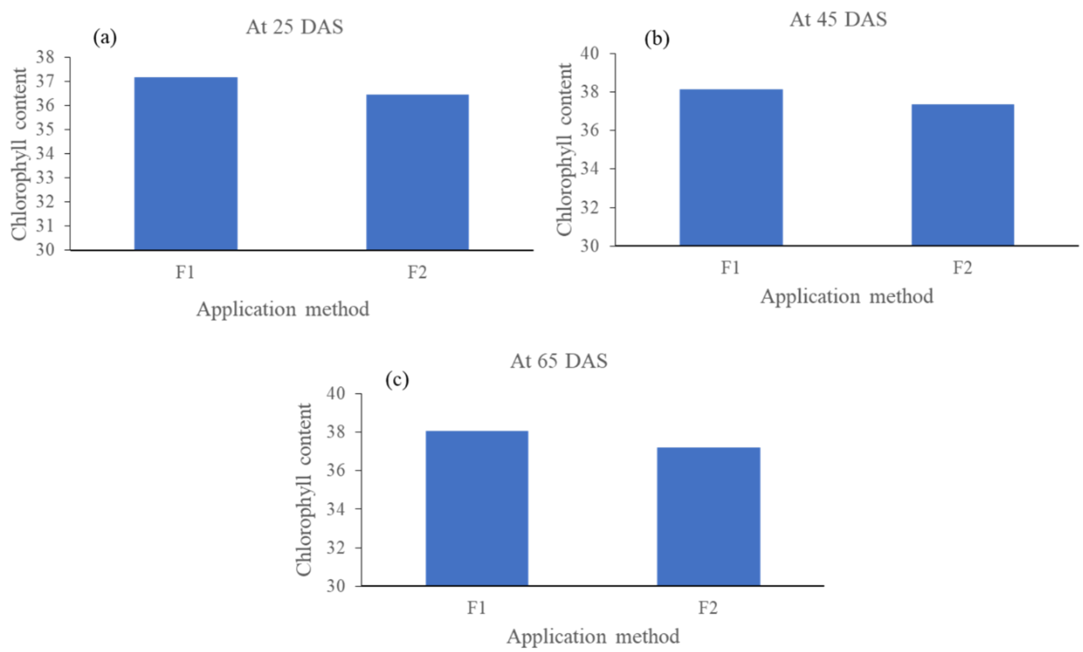

Figure 8. Effect of micronutrient application methods on chlorophyll content at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.5 Relative water content

The effect of micronutrient combination was significantly differed for relative water content of sunflower at different growth stages (Figure 9). Relative water content (RWC) of different treatment combinations ranged from 68.88%-75.45% in 25 DAS, 64.50%-72.37% in 50 DAS and 64.64%-71.38% at 75 DAS. Treatment combination of boron and zinc (T_5) gave the highest RWC at 25 and 75 DAS. At 50 DAS highest relative water content (72.37%) was observed from the combined application of boron, manganese and zinc (T_7).

The application method of micronutrients has no significant variation on relative water content at any growth stages (Figure 10). Foliar application of micronutrients (F_2) slightly showed better relative water content than soil application (F_1) at all the growth stages. At 25 DAS (72.38%), 50 DAS (68.76%) and 75 DAS (67.81%) numerically higher relative water content was observed by the foliar application of micronutrients.

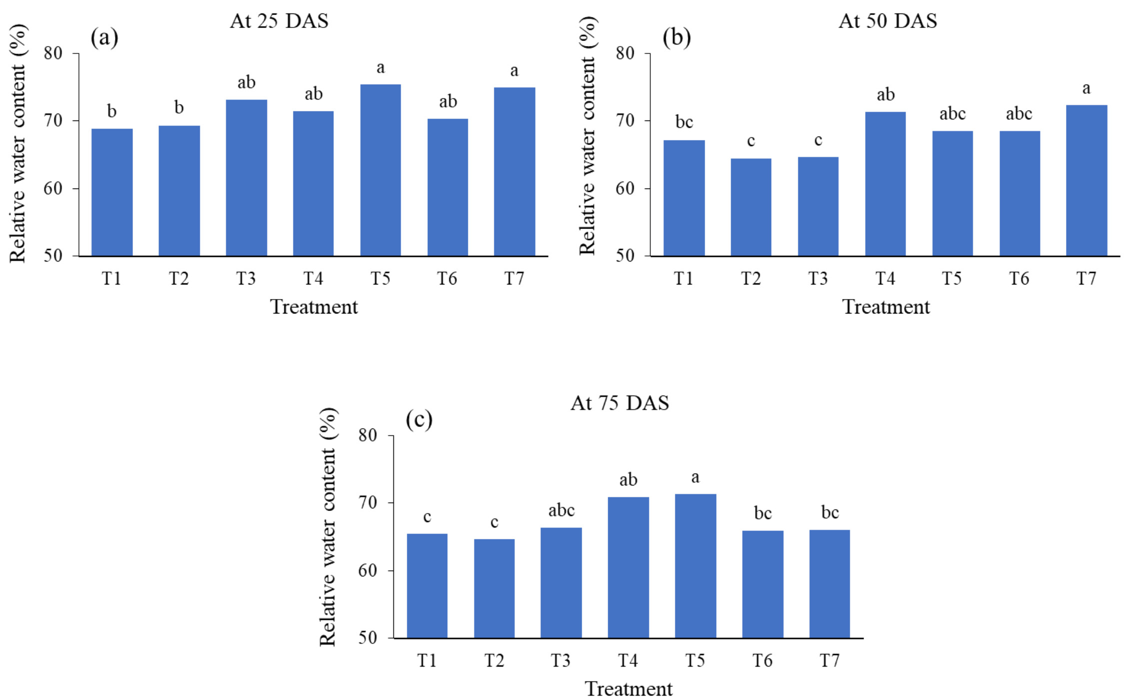

Figure 9. Effect of different micronutrients on relative water content at different days after sowing (DAS) of sunflower. (a) 25 DAS (b) 50 DAS (c) 75 DAS [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

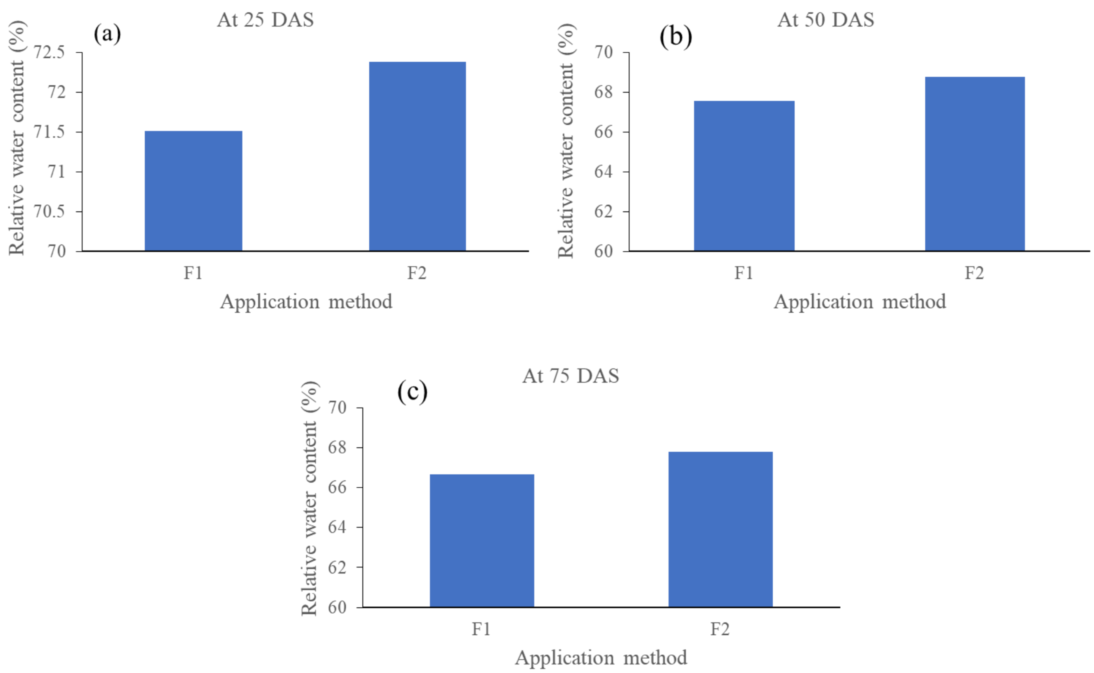

Figure 10. Effect of micronutrient application methods on relative water content at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.6 Total dry matter production

Dry matter production of a plant indicates the potentiality of total crop production of a plant. Total dry matter of sunflower plant was measured at 25, 50 and 75 DAS. It was evident that significant variation was found in total dry matter accumulation at different growth stages due different levels of treatment combinations (Figure 11). At 25 DAS the highest dry matter weight (2.58 g) was resulted from the treatment combination of boron, manganese and zinc (T_7). At 50 (5.82 g) and 75 DAS (2.35 g) maximum total dry matter production was found from the combination of boron and zinc (T_5). At 50 DAS the dry matter accumulation was maximum.

The application methods of different micronutrients have no significant difference to accumulate the total dry matter weight (DMW) on sunflower plant during any growth stages (Figure 12). At 25 (2.21 g) and 75 DAS (2.03 g) higher total dry matter weight was found by applying micronutrients in soil (F_1). At 50 DAS numerically higher total dry matter production (5.06 g) was observed by foliar application of micronutrients (F_2).

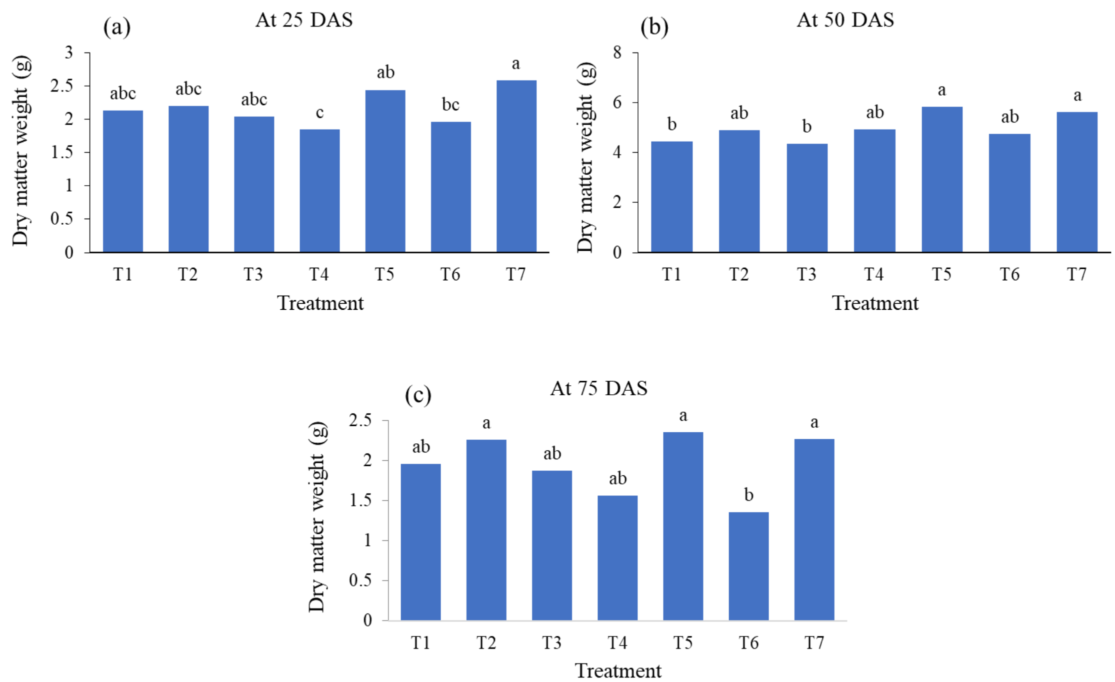

Figure 11. Effect of different micronutrients on dry matter weight at different days after sowing (DAS) of sunflower. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

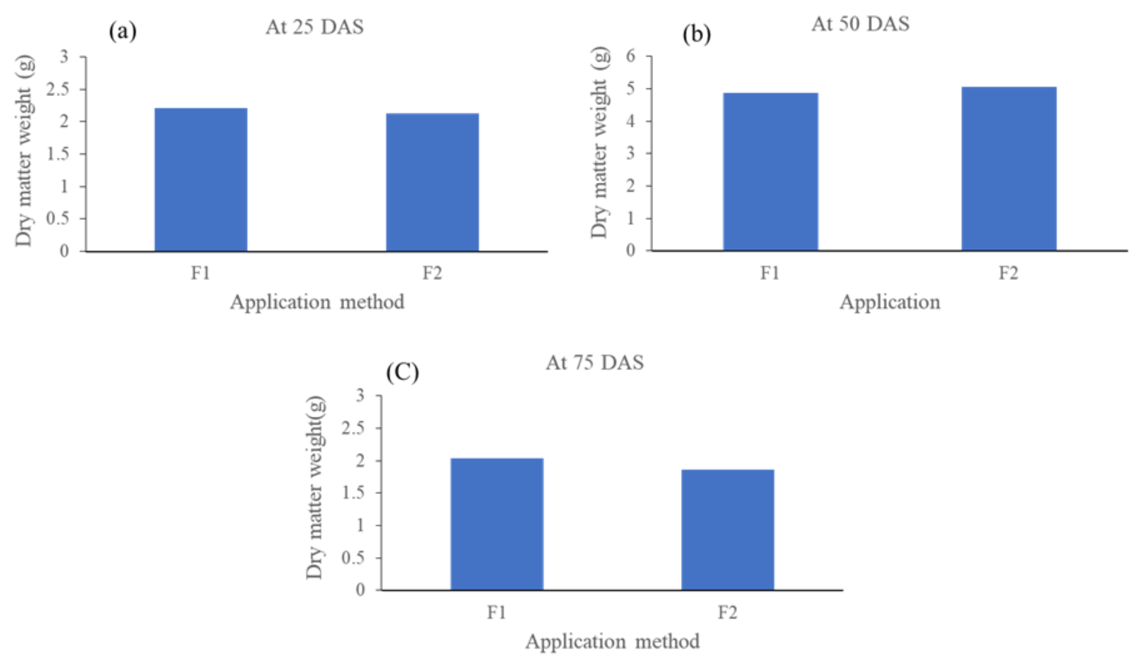

Figure 12. Effect of micronutrient application methods on dry mater weight at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.7 Crop growth rate and relative growth rate

The treatment combination effect of micronutrients significantly differed for crop growth rate (CGR) of sunflower at different growth stages (Figure 13). Crop growth rate of different treatment combinations ranged from 0.13-1.30 g $day^{-1}m^{-2}$ during 25-50 DAS and 0.32-1.15 g $day^{-1}m^{-2}$ during 50-75 DAS.

During 25-50 DAS the highest crop growth rate (1.30 g $day^{-1}m^{-2}$) was observed from the treatment combination of manganese and zinc (T_6) and the lowest CGR (0.13 g $day^{-1}m^{-2}$) resulted from the solo application of zinc (T_3). During 50-75 DAS, CGR was highest (1.15 g $day^{-1}m^{-2}$) from the combined application of manganese and zinc (T_6).

There was no significant effect of application methods of different levels of micronutrients at the growth stages of sunflower (Figure 14). No statistical difference on CGR was observed from the application method at two growth stages. During 25-50 DAS (0.52 g $day^{-1}m^{-2}$) and 50-75 DAS (0.71 g $day^{-1}m^{-2}$), numerically higher CGR was obtained from soil application of micronutrient treatments (F_1).

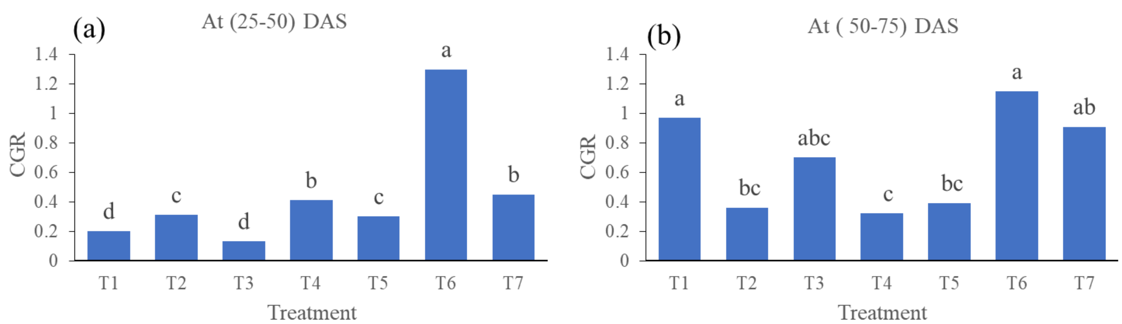

Figure 13. Effect of different micronutrients on crop growth rate at different days after sowing (DAS) of sunflower. (a) 25-50 DAS (b) 50-75 DAS. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

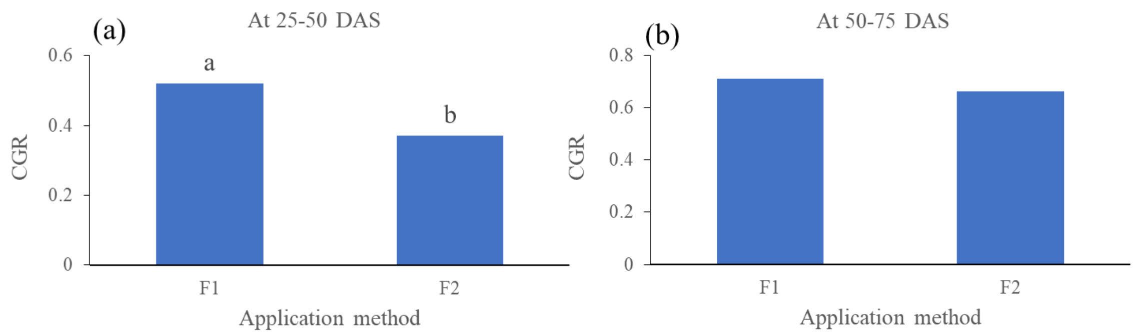

Figure 14. Effect of micronutrient application methods on crop growth rate at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

Significant variation on relative growth rate (RGR) was not observed due to different levels of treatment combinations (Figure 15). During 25-50 DAS (0.08 g g^{-1} day^{-1}) and 50-75 DAS (0.05 g $g^{-1}day^{-1}$) numerically highest RGR was obtained with combined application of boron and zinc micronutrient (T_5).

Application method of different treatments were not significantly influenced the relative growth rate at any growth stages also (Figure 16). During 25-50 DAS, both soil application method (F_1) and foliar application method (F_2) showed equal RGR (0.05 g g^{-1} day^{-1}) numerically. During 50-75 DAS, numerically higher RGR (0.04 g g^{-1} day^{-1}) was observed with foliar application of micronutrient treatments (F_2).

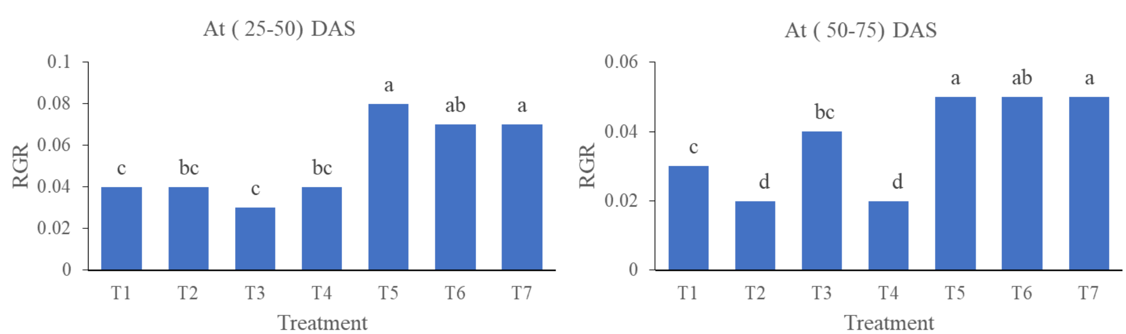

Figure 15. Effect of different micronutrients on relative growth rate at different days after sowing (DAS) of sunflower. (a) 25-50 DAS (b) 50-75 DAS. [Here, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

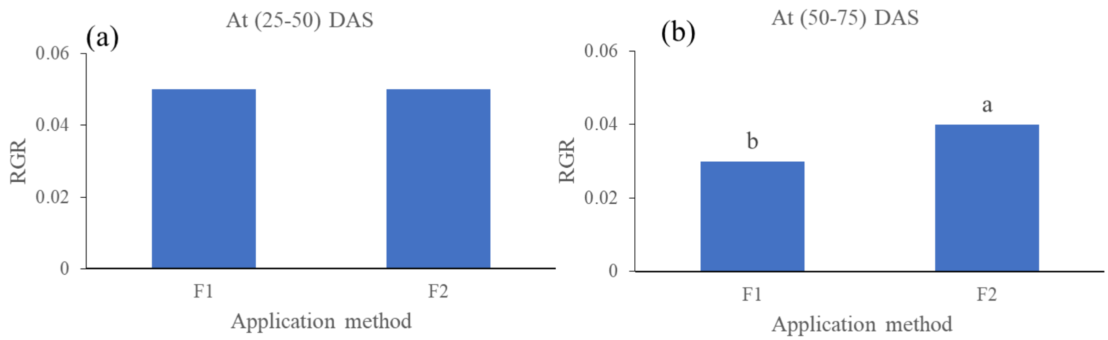

Figure 16. Effect of micronutrient application methods on relative growth rate at different days after sowing (DAS) of sunflower. [Here, F_1=Soil application, F_2= Foliar application. Mean was calculated from 3 replications from each treatment.]

4.1.8 Floral head diameter

Different levels of treatment combination had significant role in the head diameter (cm) of sunflower after the harvesting (Figure 17). The widest floral head (14.78 cm) was found with the treatment combination of boron and zinc (T_5). The shortest floral head (12.22 cm) was obtained by the combined application of boron and manganese (T_4). From figure 17 it was revealed that the floral head diameter was not influenced significantly due to the application method of different micronutrients. Numerically the foliar application of micronutrients (F_2) showed wider result (13.7 cm) than the soil application (F_1) (13.49 cm).

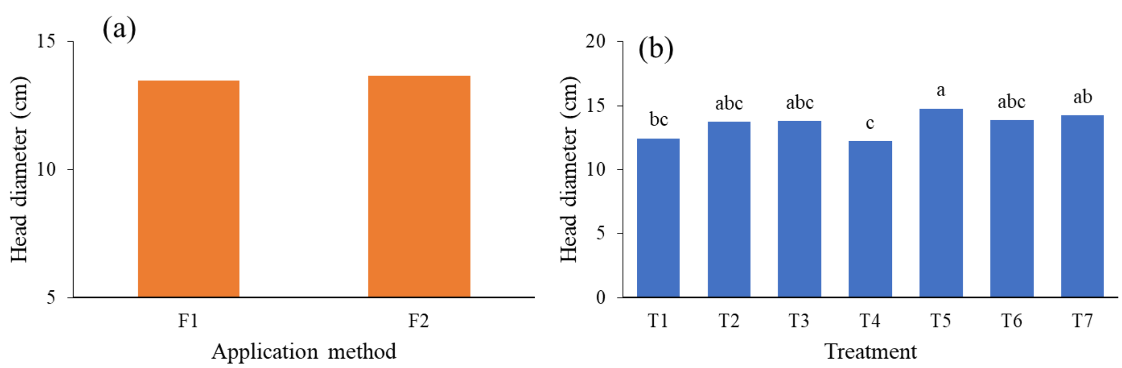

Figure 17. Effect of application method (a) and treatment combination (b) on floral head diameter of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Zn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.9 Number of seeds head^{-1}

The effect of different levels of treatment combination exerted significant influence on the number of seeds head^{-1} of sunflower (Figure 18). Combination of boron and zinc (T_5) produced the highest number of seeds head^{-1}(565), which was followed by combination of boron, manganese and zinc (T_7) (520). The lowest seed head^{-1} was found with the solo application of boron (T_1) (357). From figure 18, it was revealed that, number of seeds head^{-1} was statistically or numerically differed due to the application method of micronutrients. Higher seed head^{-1}(495) obtained with the foliar application (F_2) and lower seed head^{-1}(452) found from the soil application of micronutrient treatments (F_1).

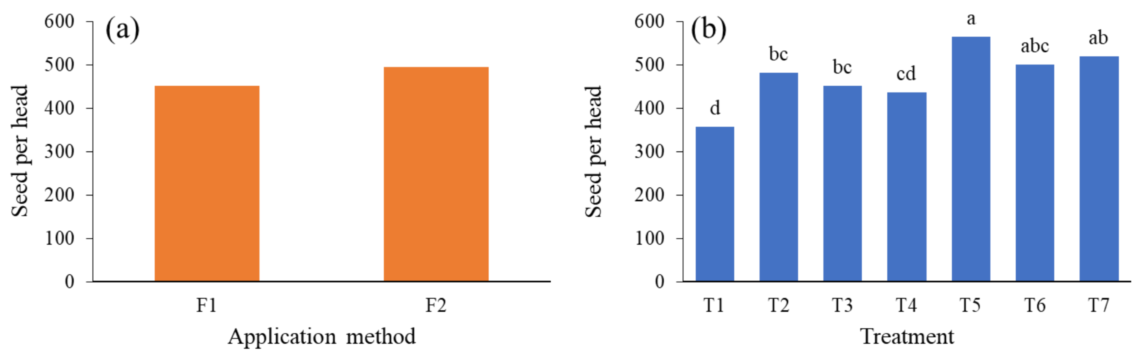

Figure 18. Effect of application method (a) and treatment combination (b) on seed plant^{-1} of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.10 Thousand-seed weight

The effect of treatment combination levels on thousand seed weight of sunflower was significant (Figure 19). The highest thousand seed weight (64.83 g) was recorded by the treatment combination of boron and zinc (T_5) which is at par with combined application of boron, manganese and zinc (T_7) (63.67 g). The lowest thousand seed weight (46.83 g) was observed from the solo application of boron (T_1).

There was no significant pairwise difference between the mean performance of application methods. Numerically higher thousand seed weight (58.09 g) obtained with soil application method (F_1) and lower seed weight (55.07 g) was found from (F_2).

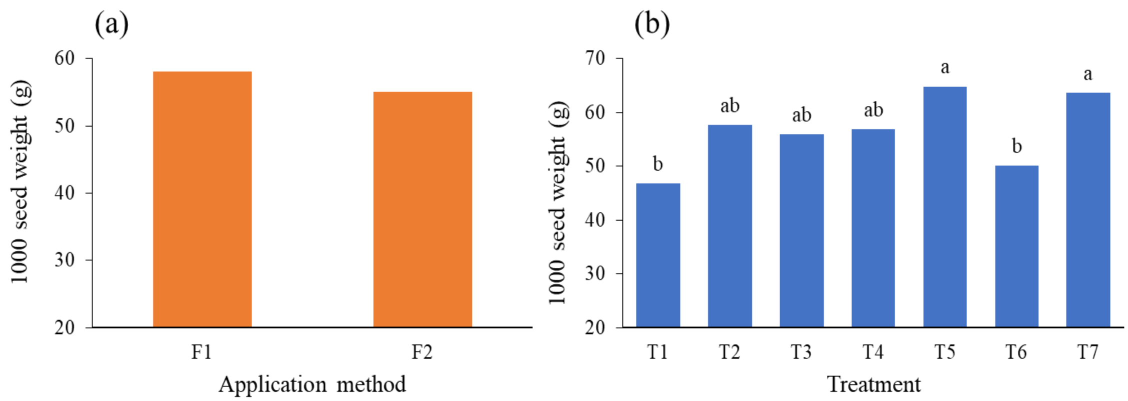

Figure 19. Effect of application method (a) and treatment combination (b) on thousand seed weight of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.11 Seed yield

Significant variation was observed in seed yield by applying different levels of treatment combination (Figure 20). Combined application of manganese and zinc (T_6) showed numerically highest seed yield plant^{-1} (22.13 g), followed by combined application of boron, manganese and zinc (T_7) (21.68 g) and combined treatment of boron and zinc (T_5) (21.39 g).

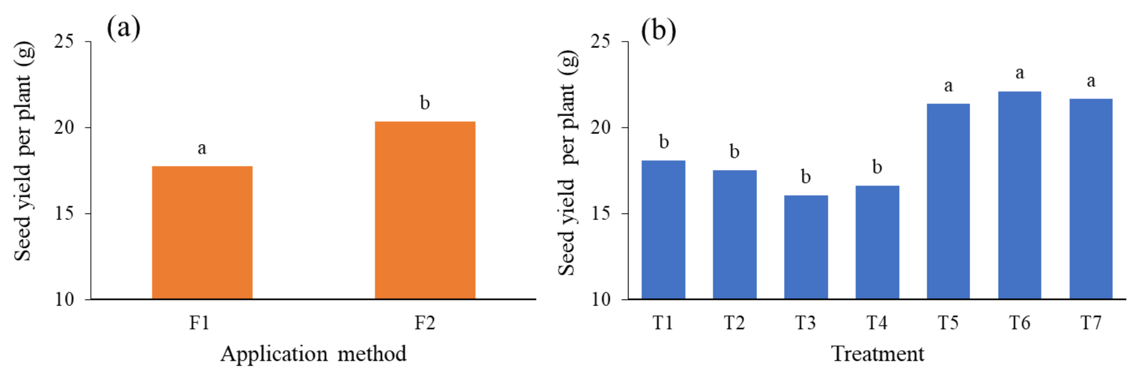

Figure 20. Effect of application method (a) and treatment combination (b) on seed yield plant^{-1} of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

The seed yield plant^{-1} was significantly influenced by the application methods of different micronutrient treatments (Figure 20). Foliar application of micronutrient (F_2) showed higher seed yield (20.37 g) than soil application method (F_1) (17.75 g)

4.1.12 Stover yield

The effect of treatment combinations at different levels was found significant in respect of stover yield of sunflower statistically similar to T_6 and T_5 (Figure 21). Combination of boron, manganese and zinc (T_7) produced the highest stover yield plant^{-1} (61.73 g). However, the lowest stover yield plant^{-1} (41.67 g) was observed with the solo application of zinc (T_3). The application method of different levels of micronutrient treatments exerted significant variation on stover yield of sunflower (Figure 21). Stover yield was higher (55.12 g) in foliar application of micronutrients (F_2) and lowest stover yield (48.74 g) found from soil application of micronutrient (F_1).

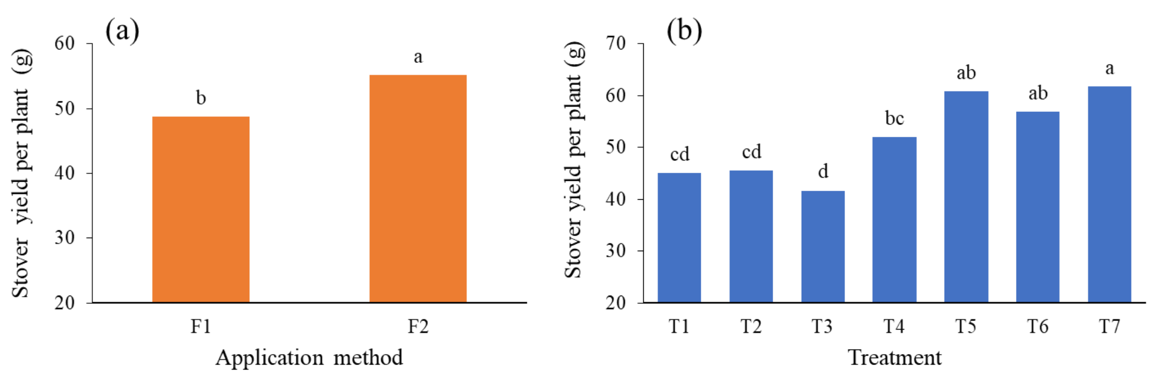

Figure 21. Effect of application methods (a) and treatment combination (b) on stover yield plant^{-1} of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.13 Biological yield

Effect of treatment combination of different treatments exerted significant variation on biological yield (Figure 22). Biological yield was highest (102.17 g) in combined application of boron, manganese and zinc (T_7) which is at par with combined application of boron and zinc (T_5) (101.76 g) and T_6. The lowest numerical biological yield (68 g) was found from the mixed treatment of boron and manganese (T_4) (68 g). Effect of application method of treatments was observed significant on biological yield (Figure 22)

Numerically higher biological yield (87.86 g) obtained with foliar application method (F_2) and the lower biological yield (78.31 g) was found the soil application of micronutrient (F_1).

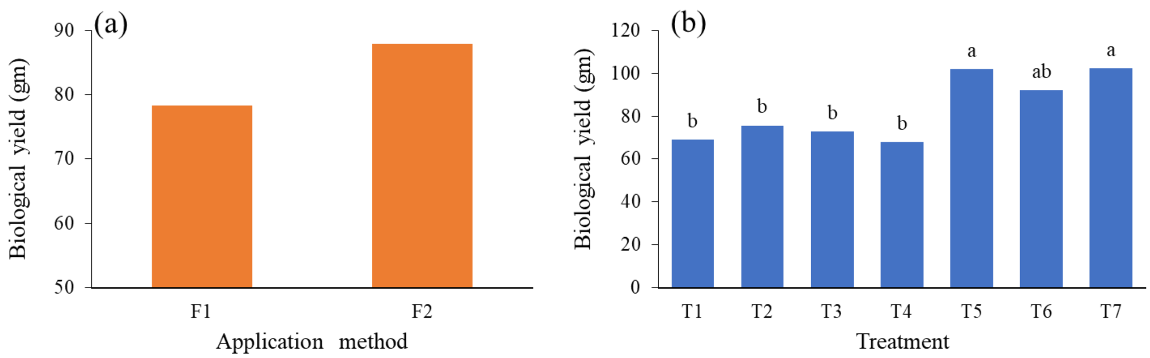

Figure 22. Effect of application method (a) and treatment combination (b) on biological yield of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.14 Harvest index

Effect of different treatment combinations exerted significant variation on harvest index (%). (Figure 23). Harvest index was highest (36.82%) in combined application of boron, manganese and zinc (T_7) and the lowest harvest index (21.46%) was found from solo application of manganese (T_3).

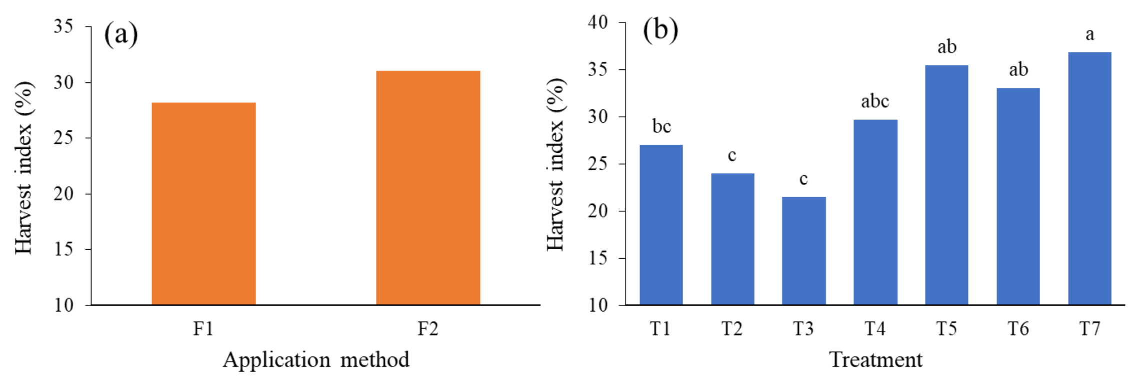

Figure 23. Effect of application method (a) and treatment combination (b) on harvest index (%) of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

There was no significant effect of micronutrient application method on harvest index. Foliar application of micronutrient (F_2) showed numerically higher harvest index (31.03%) than soil application method (F_1) (28.22%).

4.1.15 Oil percentage

Significant variation in oil percentage of sunflower was observed due to different levels of treatment combination (Figure 24). Maximum oil percentage (43.18%) was obtained with the combined application of boron, manganese and zinc (T_7), which is similar with the solo application of manganese (T_2) (42.58%). However, the lowest oil percentage (39.28%) was observed by the combined application of manganese and zinc (T_5). Oil percentage was not significantly affected by the application method of micronutrients (Figure). Soil application of micronutrient (F_1) showed numerically higher oil percentage (41.24%) than the foliar application method (F_2) (40.92%).

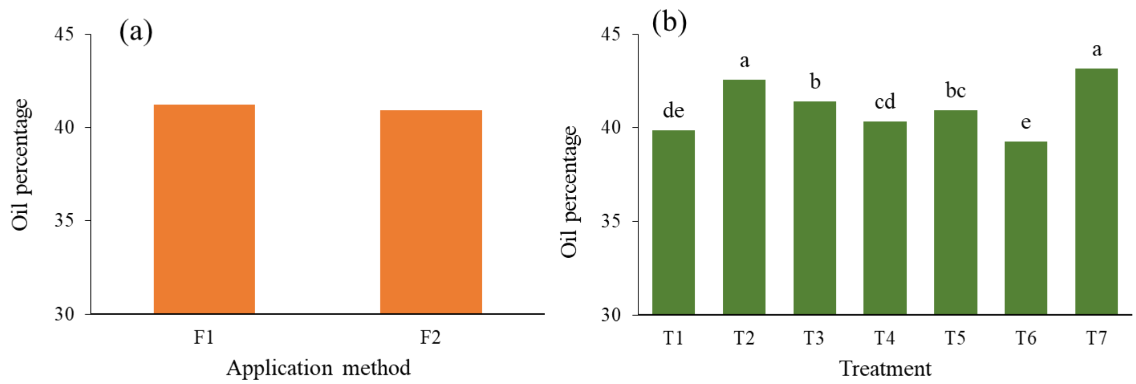

Figure 24. Effect of application method (a) and treatment combination (b) on oil percentage of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.16 Seed moisture percentage

There was a variation in the value of seed moisture percentage of sunflower was observed with the different micronutrient's treatment (Figure 25). From the treatment combination of manganese and zinc (T_6) highest seed moisture (13.76%) was observed, followed by treatment combination of boron, manganese and zinc (T_7) (13.74%). Meanwhile lowest seed moisture (9%) was obtained with mixed application of boron and zinc (T_5).

Significant variation was found on seed moisture (%) of sunflower from different application methods of micronutrients. Soil application of micronutrients (F_1) showed higher seed moisture (11.82%) than the foliar application of micronutrients (F_2) (11.20%).

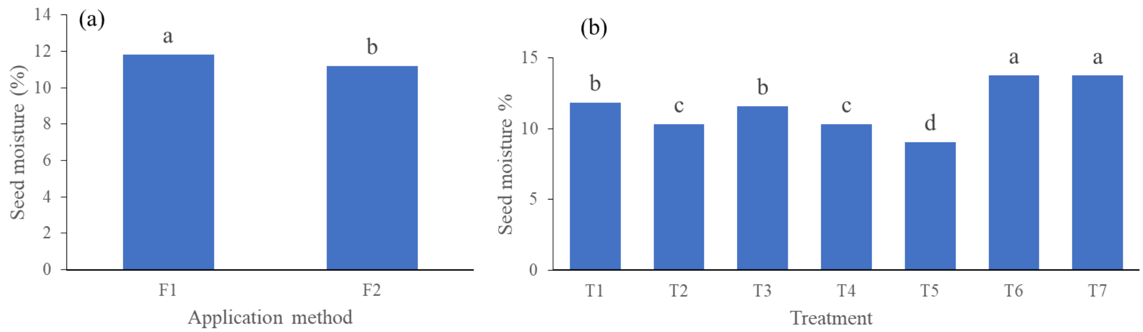

Figure 25. Effect of application method (a) and treatment combination (b) on seed moisture (%) of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.1.17 Protein percentage

Protein percentage of sunflower plant was significantly influenced by the effect of different treatment combinations (Figure 26). Highest protein percentage (48.83%) was found from the combined application of manganese and zinc (T_6), at par with combined application of boron, manganese and zinc (T_7) (48.22%). The lowest protein percentage observed by the solo application of boron (T_1) (39.10%).

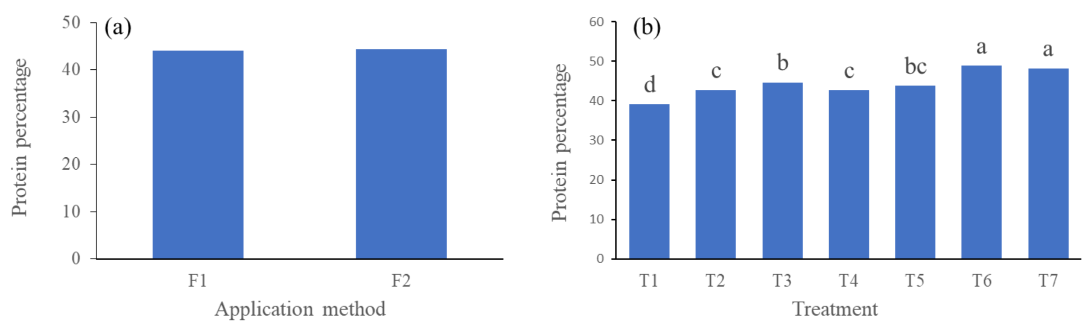

Figure 26. Effect of application method (a) and treatment combination (b) on protein percentage (%) of sunflower. [Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

There was no statistical difference between the two micronutrient application methods (Figure 26). Numerically better protein percentage (44.39%) obtained with foliar application method (F_2) and lower protein percentage (44.16%) observed by soil application of micronutrients (F_1).

4.2 Effect of treatment interaction on different parameters of sunflower

4.2.1 Plant height

The interaction effect of micronutrients and their application methods was significantly differed for plant height of sunflower at different growth stages (Table 3). Plant height of different treatment interactions ranged from 18.08-26.5 cm in 25 DAS, 49.28-84.61 cm in 45 DAS and 103.46-144.94 cm at 65 DAS. Regardless of treatment combination interaction with application method, plant height increased progressively up to maturity stage.

The soil application of all three micronutrients Boron, Manganese and Zinc (T_7F_1) gave the higher plant height at 25 and 65 DAS. The highest plant height (144.94 cm) was found by the soil application of B, Mn and Zn (T_7F_1). It is 40.09% greater than the lowest result T_1F_1 (only boron application through soil) 103.46 cm. In general, the foliar application of B, Mn, Zn gave higher plant height most of the time.

The previous result showed that, the maximum sunflower plant height resulted by the application of zinc at 2.00% level (Keerio *et al.*, 2020). The study suggests that Zn can be employed as a foliar form for improving sunflower yields and quality, especially in regions where the soils are Zn deficient. The results itself agreed with Praksh and Halaswamy (2004) who suggested that the superiority of plant height could be attributed to high available of nutrient application.

In terms of treatment method several studies showed that mixture of two or more micronutrients gave the highest growth parameters in oilseed crops. Combined (Zn, B and Mo) foliar application of micronutrient recorded significantly higher plant height (176 cm) than the control in Indian mustard (Tejeswara Rao and Subbaiah, 2006).

Significant difference was observed in height of sunflower with foliar application of B+ Mn, but their combined effects were more significant (Nusrat and Rafiq, 2011).

Table 3. Interaction effect of micronutrients and application method on plant height at different DAS of sunflower

Treatment Interaction	Plant height (cm)		
	25 DAS	**45 DAS**	**65 DAS**
T_1F_1	20.82 abc	49.28 c	103.46 e
T_1F_2	23.59 abc	63.69 bc	121.24 b-e
T_2F_1	22.17 abc	72.11 ab	127.28 a-d
T_2F_2	20.15 bc	68.64 abc	133.00 a-d
T_3F_1	18.08 c	64.68 abc	116.86 de
T_3F_2	22.85 abc	79.27 ab	137.36 a-d
T_4F_1	20.62 bc	60.74 bc	117.30 cde
T_4F_2	20.58 bc	64.69 abc	121.40 b-e
T_5F_1	24.72 ab	75.54 ab	142.00 ab
T_5F_2	25.57 ab	80.50 ab	142.46 a
T_6F_1	22.61 abc	67.99 abc	130.82 a-d
T_6F_2	21.23 abc	75.40 ab	138.11 abc
T_7F_1	26.50 a	80.71 ab	144. 94 a
T_7F_2	24.56 ab	84.61 a	144.57 a
CV (%)	**15.39**	**17.61**	**9.59**
LSD (0.05)	**5.79**	**20.85**	**20.93**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.2 Number of leaf plant^{-1}

Significant difference in number of leaves plant^{-1} was observed from the interaction of micronutrients and their application method on different growth stages (Table 4). Number of leaves ranged from 5-7.33 at 25 DAS, 11.67-16.67 at 45 DAS and 16-20.33 at 65 DAS. The soil application of all 3 micronutrients (B, Mn, Zn) denoted by T_7F_1 showed the highest leaf numbers on 25 DAS (7.33) and 65 DAS (20.33). At 45 DAS maximum leaf number (16.67) was observed from the foliar application of boron and zinc (T_5F_2) which was followed by T_7F_1 (16.33).

Manganese is part of the make-up of enzymes, it also helps in photosynthesis and metabolic functions of plants. Boron assists in the metabolic function of plant and aids in cell division. The maximum leaf number was found by the application of boron, manganese and zinc might be due to the role of these micronutrients in plant metabolism. Which might be the result of maximum leaf number.

A previous result showed that leaf number is significantly increased in plants sprayed with foliar minerals irrespective to their growth under non-saline or saline irrigation (Nusrat Jabeen and Rafiq Ahmed,2011). The results of the present study are in agreement with those of (Nusrat Jabeen and Rafiq Ahmed, 2011).

Table 4. Interaction effect of micronutrients and application method on number of leaf plant^{-1} at different DAS of sunflower

Treatment Interaction	25 DAS	45 DAS	65 DAS
T_1F_1	5.00 d	13.00 cde	17.333 bc
T_1F_2	6.67 abc	14.33 a-e	17.67 abc
T_2F_1	6.33 abc	13.33 cde	16.33 c
T_2F_2	5.67 cd	11.67 e	17.00 bc
T_3F_1	6.00 bcd	12.0 de	17.33 bc
T_3F_2	7.00 ab	14.67 a-d	17.67 abc
T_4F_1	6.00 bcd	13.67 b-e	16.00 c
T_4F_2	6.00 cd	13.33 cde	17.67 abc
T_5F_1	6.00 bcd	14.67 a-d	19.67 ab
T_5F_2	7.00 ab	16.67 a	18.67 abc
T_6F_1	7.00 ab	14.33 a-e	19.67 ab
T_6F_2	6.00 bcd	15.00 abc	17.33 bc
T_7F_1	7.33 a	16.33 ab	20.33 a
T_7F_2	6.33 abc	15.67 abc	18.33 abc
CV (%)	**11.51**	**12.39**	**9.29**
LSD (0.05)	**1.22**	**2.95**	**2.79**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.3 Leaf area Index

Leaf area index is one of the most important agronomic traits to consider the growth and development of a plant. Significant variation was observed due to different levels of treatment interactions with application method at all the three growth stages of sunflower plant (Table 5).

At 25 DAS leaf area index value ranged from 0.07-0.26. At 45 DAS and 65 DAS leaf area index of different interaction ranged from 0.62-2.55 and 1.77-3.20. The foliar application of boron and zinc (T_5F_2) showed the maximum leaf area index at 45 DAS and 65 DAS numerically. But at 25 DAS numerically highest leaf area index (0.26) was obtained with soil application of boron, manganese and zinc (T_7F_1).

Sunflower physiological traits affected by different zinc and boron levels at flowering stage was observed by previous research work. (Siddiqui *et al.,* 2009). Siddique *et al*. (2009) reported that the application of zinc and boron significantly increased the values of dry matter, leaf area index, crop growth rate and net assimilation ratio at flowering stage of sunflower. The optimal response was noted with the combined application of 15-1.5 Zn-B kg ha^{-1}. The results of the present study are in agreement with the mentioned previous research work.

Table 5. Interaction effect of micronutrients and application method on leaf area indices at different DAS of sunflower

Treatment interaction	25 DAS	45 DAS	65 DAS
T_1F_1	0.071 d	0.62 f	1.78 d
T_1F_2	0.13b cd	1.12 def	2.17 cd
T_2F_1	0.15 bcd	1.35 c-f	2.22 cd
T_2F_2	0.10 bcd	1.38 b-f	2.92 abc
T_3F_1	0.11 bcd	1.16 c-f	2.23 bcd
T_3F_2	0.17 abc	1.62 b-e	2.46 a-d
T_4F_1	0.09 cd	0.854 ef	1.77 d
T_4F_2	0.11 bcd	1.31 c-f	2.11 cd
T_5F_1	0.14 bcd	1.73 bcd	3.17 ab
T_5F_2	0.19 ab	2.550 a	3.20 a
T_6F_1	0.18 abc	1.31 c-f	2.76 abc
T_6F_2	0.12 bcd	1.78 a-d	2.66 a-d
T_7F_1	0.26 a	1.91 abc	2.78 abc
T_7F_2	0.15 bcd	2.16 ab	2.75 abc
CV (%)	**38.63**	**31.66**	**22.74**
LSD (0.05)	**0.091**	**0.79**	**0.95**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.4 SPAD value

Significant variation in SPAD value was observed at different growth stages of sunflower due to different levels of interaction of treatment with application method (Table 6).

SPAD value of different treatment interactions ranged from 33.52-39.42 at 25 DAS, 35.41-40.88 at 45 DAS, 36.01-39.74 at 65 DAS. At 25, 45 and 65 DAS numerically maximum SPAD value was obtained with soil application of manganese and zinc (T_6F_1), soil application of boron, manganese and zinc (T_7F_1) and foliar application of boron, manganese and zinc (T_7F_2) respectively.

The SPAD meter reading is related to the amount of chlorophyll present in the leaf. The SPAD meter measures the difference between the transmittance of a red (650 nm) and an infrared (940 nm) light through the leaf. It gives a three-digit SPAD value (Uddling *et al*., 2007).

Previously in Iran an experiment was conducted about the influence of micronutrients on leaf chlorophyll content of sunflower. the maximum amount of leaf chlorophyll content was obtained from foliar application of zinc and manganese, single foliar application of manganese and single foliar application of zinc respectively (Babeidan *et al*., 2011).

Another experiment showed that, the highest amount of SPAD unit was recorded for plants grown by iron and zinc application with farm yard manure. Application of Zn and Fe increased SPAD unit by 17% and 15% compared with conditions without the application of micronutrient (Nouraein *et al.,* 2019).

Table 6. Interaction effect of micronutrients and application method on chlorophyll content at different DAS of sunflower

Treatment Interaction	25 DAS	45 DAS	65 DAS
T_1F_1	34.94 def	35.41 e	38.73 ab
T_1F_2	33.52 f	36.33 de	36.01 b
T_2F_1	36.34 cde	37.12 cde	36.17 b
T_2F_2	37.73 abc	36.74 cde	36.57 b
T_3F_1	37.61 abc	39.22 a-d	38.69 ab
T_3F_2	37.02 a-d	39.39 abc	37.92 ab
T_4F_1	36.26 cde	37.06 cde	38.36 ab
T_4F_2	36.38 cde	36.11 e	36.13 b
T_5F_1	36.80 bcd	37.92 b-e	36.90 ab
T_5F_2	34.20 ef	35.60 e	36.52 b
T_6F_1	39.42 a	39.28 a-d	39.60 a
T_6F_2	38.63 abc	36.97 cde	37.47 ab
T_7F_1	38.97 ab	40.88 a	37.90 ab
T_7F_2	37.72 abc	40.32 ab	39.74 a
CV (%)	**4.09**	**4.65**	**4.68**
LSD (0.05)	**2.53**	**2.95**	**2.95**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.5 Relative water content

At all growth stages of sunflower, the interaction effect of treatment with application method significantly influenced the relative water content (RWC) (Table 7). The highest relative water content at 25 DAS (76.10%) was recorded by the interaction of soil application of boron and zinc (T_5F_1) and at par with foliar application of boron, manganese and zinc (T_7F_2) (75.61%). At 50 DAS the maximum RWC (72.88%) was resulted by the interaction of foliar application of boron, manganese and zinc (T_7F_2), where the lowest result (62.40%) was observed from the treatment of manganese as a single micronutrient by soil application. At 75 DAS the relative water content of different treatment interactions ranged from 62.51-71.72%. The highest RWC was found from the foliar application of boron and zinc (T_5F_2) Where the lowest result obtained from the foliar application of boron (T_1F_2).

In a previous study about determining the effects of micronutrients and organic fertilizers on yield and growth characteristics of sunflower, result showed that, highest leaf relative water content was observed by combined application of iron and zinc (Nourein *et al.*, 2019). Zinc played an important role to accelerate the relative water content alongside with boron application. Overall, the mixture of more than one micronutrient affect positively to the relative water content. The research findings at par with the present experiment.

Table 7. **Interaction effect of micronutrients and application method on relative water content at different DAS of sunflower**

Treatment Interaction	25 DAS	50 DAS	75 DAS
T_1F_1	68.38 b	67.69 abc	68.38 abc
T_1F_2	69.38 ab	66.73 bc	62.51 c
T_2F_1	68.35 b	62.40 c	63.81 bc
T_2F_2	70.37 ab	66.60 bc	65.48 abc
T_3F_1	72.44 ab	66.74 bc	63.93 bc
T_3F_2	73.84 ab	62.59 c	68.89 abc
T_4F_1	69.16 ab	72.04 ab	70.91 ab
T_4F_2	73.83 ab	70.65 ab	70.79 ab
T_5F_1	76.10 a	65.96 bc	71.03 ab
T_5F_2	74.80 ab	71.12 ab	71.72 a
T_6F_1	71.91 ab	66.22 bc	65.60 abc
T_6F_2	68.80 b	70.78 ab	66.20 abc
T_7F_1	74.23 ab	71.86 ab	62.94 c
T_7F_2	75.61 ab	72.88 a	69.03 abc
CV (%)	**6.04**	**5.37**	**6.57**
LSD (0.05)	**7.29**	**6.14**	**7.41**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.6 Total dry matter production

Dry matter is what remains after all the water is evaporated or reduced from a plant. Total dry matter (TDM) indicates the potentiality of total economic production of a plant. Significant effect was found in the total dry matter content at different growth stages except at 75 DAS, due to the interaction of different levels of micronutrient treatments along with application method (Table 8). During the growth and vegetative stages dry matter weight increased progressively regardless of treatment interaction.

At 25 DAS, highest dry matter weight (2.69 g) was found with the soil application of boron, manganese and zinc soil application (T_7F_1). At 50 DAS maximum total dry matter (6.17 g) was obtained from foliar application of boron and zinc (T_5F_2). At 75 DAS the total dry matter weigh was reduced compared to the findings at 50 DAS. At 75 DAS the highest total dry matter (2.37 g) was obtained with the foliar application of boron, manganese and zinc.

A significant difference was observed in fresh and dry biomass of plant with foliar spray of micronutrients boron and manganese on growth and biochemical activities in sunflower under saline condition (Nusrat Jabeen and Rafiq Ahmed, 2011).

At post-anthesis stage, application of boron of 3.39 kg ha^{-1} performed best in producing maximum dry matter content (Shehzad *et al*., 2016).

Table 8. Interaction effect of micronutrients and application method on total dry matter weight at different DAS of sunflower

Treatment Interaction	25DAS	50 DAS	75 DAS
T_1F_1	1.93 ab	4.19 b	1.80 a
T_1F_2	2.33 ab	4.7 ab	2.05 a
T_2F_1	2.14 ab	4.78 ab	2.24 a
T_2F_2	2.26 ab	4.96 ab	2.27 a
T_3F_1	2.15 ab	4.38 b	2.31 a
T_3F_2	1.93 ab	4.34 b	1.43 a
T_4F_1	1.84 b	5.28 ab	1.85 a
T_4F_2	1.85 b	4.56 ab	1.26 a
T_5F_1	2.49 ab	5.48 ab	2.34 a
T_5F_2	2.39 ab	6.17 a	2.35 a
T_6F_1	2.22 ab	4.25 b	1.44 a
T_6F_2	1.69 b	5.24 ab	1.26 a
T_7F_1	2.69 a	5.77 ab	2.16 a
T_7F_2	2.47 ab	5.47 ab	2.37 a
CV (%)	**22.46**	**19.55**	**35.66**
LSD (0.05)	**0.82**	**1.63**	**1.16**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications.]

4.2.7 Crop growth rate and relative growth rate

The interaction effect of micronutrients and their application methods showed a significant variation on crop growth rate at both 25-50 DAS interval and 50-75 DAS interval (Table 9). At 25-50 DAS time period highest crop growth rate (1.61 g day^{-1} m^{-2}) was observed with soil application of manganese and zinc (T_6F_1) and the minimum (0.08 g day^{-1} m^{-2}) was obtained from foliar application of only zinc application (T_3F_2). Similar trend was found at 50-75 DAS time period. Highest crop growth rate (1.33 g day^{-1} m^{-2}) was found with soil application of manganese and zinc (T_6F_1) and lowest result (0.28 g day^{-1} m^{-2}) was revealed with the foliar application of boron and manganese (T_4F_2).

Relative growth rate (RGR) is the rate of accumulation of new dry mass per unit of existing dry mass. Relative growth rate is a major determinant of plant competitiveness (Didon, 2002).

There was no significant effect of treatment interactions on relative growth rate (RGR), in both 25-50 DAS and 50-75 DAS growth stages of sunflower (Table 9). Relative growth rate increased at a very lower rate, sometimes decrease with age. At 25-50 DAS (0.09 g $g^{-1}day^{-1}$) and 50-75 DAS (0.06 g g^{-1} day^{-1}) numerically higher RGR observed with the foliar application of boron and zinc. Foliar application of zinc (T_3F_2) gave numerically lower relative growth rate (0.03 g g^{-1} day^{-1}) at 25-50 DAS. At 50-75 DAS foliar application of zinc (T_3F_2) and foliar application of boron and manganese (T_4F_2) both showed the lower RGR (0.02 g g^{-1} day^{-1}) numerically.

The effects of the fertility of zinc and boron micronutrient on sunflower physiological parameters were observed in a previous experiment. This micronutrient treatment showed maximum response in dry matter (1150.12 g m^{-2}), leaf area index (5.26), leaf area duration (51.34 days), crop growth rate (7.39 g day^{-1} m^{-2}) (Siddique *et al.*, 2009). The result of the experiment was also supported by (Patil *et al*, 2006). Combined application of zinc and boron gave the highest crop growth rate compare to control treatment.

Observations of a previous experiment showed that, combination treatment of micronutrients boron@ 0.3%, zinc @ 0.05% and sulfur foliar spray increased the growth parameters such as CGR, RGR, NGR (Ravikumar *et al*., 2021).

Table 9. **Interaction effect of micronutrients and application method on crop growth rate and relative growth rate at different DAS of sunflower**

Treatment interaction	CGR (25-50) DAS	CGR (50-75) DAS	RGR (25-50) DAS	RGR (50-75) DAS
T_1F_1	0.22 f	0.74 abc	0.053 abc	0.03 d-h
T_1F_2	0.17 fg	1.20 ab	0.03 c	0.04 d-g
T_2F_1	0.41 e	0.33 c	0.05 abc	0.03 hi
T_2F_2	0.20 fg	0.39 c	0.04 bc	0.02 ghi
T_3F_1	0.19 fg	0.78 abc	0.04 bc	0.03 e-i
T_3F_2	0.08 g	0.62 abc	0.03 c	0.04 b-e
T_4F_1	0.21 f	0.37 c	0.05 abc	0.03 f-i
T_4F_2	0.60 d	0.28 c	0.04 bc	0.02 i
T_5F_1	0.22 f	0.45 bc	0.07 ab	0.04 c-f
T_5F_2	0.38 e	0.34 c	0.09 a	0.06 a
T_6F_1	1.61 a	1.33 a	0.05 abc	0.04 d-g
T_6F_2	0.98 b	0.97 abc	0.08 a	0.06 ab
T_7F_1	0.75 c	0.99 abc	0.06 abc	0.04 bcd
T_7F_2	0.15 fg	0.82 abc	0.08 a	0.05 abc
CV (%)	**16.77**	**69.14**	**40.33**	**23.67**
LSD (0.05)	**0.12**	**0.79**	**0.037**	**0.015**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.8 Floral head diameter

The effect of interaction between treatment of micronutrients and application method was not found to be significant in respect of floral head diameter (cm) (Table 10). The foliar application of combined treatment of boron and zinc (T_5F_2) produced the widest head diameter (15.17 cm) numerically, followed by foliar application of boron, manganese and zinc (T_7F_2) (14.49 cm) and soil application of boron and zinc (T_5F_1) (14.40 cm). However, the lowest result (12.16 cm) observed from the soil application of boron and manganese (T_4F_1). The highest result is 24.76% higher than the lowest head diameter result. In a previous study on the physiological trait of sunflower, the foliar application of combined micronutrients boron and manganese resulted the largest floral head diameter (Nusrat Jabeen and Rafiq Ahmed, 2011). In a pervious study regarding the yield determining components of sunflower such as head diameter and the number of seeds head^{-1} were significantly increased with the combined micronutrient treatment of S @ 40 kg ha^{-1} as soil application and Zn @ 0.5% and B @0.3% as foliar spray during both the year of crop period (Ravikumar *et al*., 2021).

4.2.9 Number of seeds head^{-1}

Number of seeds head^{-1} was significantly influenced by the interaction effect of treatment and application method (Table 10). Combination of boron and zinc applied as foliar spray (T_5F_2) produced the highest number of seed head^{-1} (567.67) which was at par with soil application of boron and zinc (T_5F_1) (563.67), the second highest number of seed head^{-1}. The lowest seed count found from the soil application of boron (T_1F_1) (330.67). The result was corroborated with the findings of Nusrat jabeen and Rafiq ahmad (2011), who found that number of seed head^{-1} significantly increased with the application of foliar spray of micronutrients. The highest number of sunflower seed was recorded in those plants sprayed with the mixture of manganese and boron as compared to non-sprayed plants. The number of seeds head^{-1}, weight of 1000 seed, oil percentage as well as the oil yield (g plant^{-1}) was significantly increased with increasing the application of boron micronutrient application up to 600 ppm. These increases were estimated by 76.26%, 46.34% and 63.84%, respectively (Bahaa El-Din Mekki, 2015). These results are also agreed with the previous experiment obtained by Al-Amery *et al.,* (2011), and Tahir *et al.,* (2014).

4.2.10 1000 seed weight

1000 seed weight from a sunflower head is an important parameter for determining and evaluating the physiological trait. Interaction effect of different treatment combination and application method was found on 1000 seed weight of sunflower (Table 10). Highest 1000 seed weight (67 g) was found from foliar application of boron and zinc (T_5F_2) which was similar with foliar application of boron, manganese and zinc (T_7F_2) (64.33 g), soil application of boron, manganese and zinc (T_7F_1) (63 g) and soil application of boron and zinc (T_5F_1) (62.67 g). The lowest (42.67 g) was found in foliar application of boron (T_4F_2).

Findings of previous experiments revealed that, weight of 1000 g seed was highly affected by boron foliar application. Application of boron up to 600 ppm significantly increased seed weight plant^{-1}, weight of 1000 seed in sunflower plant. The highest mean performance of 1000 seed weight of sunflower was 36 g, by boron treatment and the lowest result was found in control treatment (24.60 g). Boron foliar application resulted 46.34% higher performance than the control (Bahaa El-Din Mekki, 2015).

4.2.11 Seed yield

It was observed in the table 10 that, the interaction of different levels of treatment combination and the application method significantly affected the seed yield of sunflower (Table 10). The maximum seed yield (23.87 g head^{-1}) resulted from the foliar application of manganese and zinc (T_6F_2) and the lowest performance (14.73 g head^{-1}) found from the soil application of boron as a single micronutrient (T_1F_1).

The result was supported by the previous experiment where significant response of sunflower to the application of boron, iron and zinc was seen on the seed yield. The seed yield of 757 kg ha^{-1} in control increased to the maximum of 983 kg ha^{-1} in B (0.3%) application. The maximum recorded seed yield was 29% higher than the control (Kumar *et al.*, 2009).

The application of zinc also caused significant increase in seed yield of sunflower. The significance of boron, iron and zinc on seed yield of sunflower was contended by previous research works (Prabhuraj *et al*., 1993).

Table 10. **Interaction effect of micronutrients and application method on head diameter, seed head^{-1}, thousand seed weight and seed yield of sunflower**

Treatment Interaction	Head Diameter	Seed Head^{-1}	1000-seed weight	Seed yield
T_1F_1	12.58 ab	330.67 e	51.00 bc	14.73 e
T_1F_2	12.32 b	383.67 de	42.67 c	21.40 ab
T_2F_1	13.58 ab	437.00 b-e	58.97 ab	16.13 de
T_2F_2	13.93 ab	528.00 ab	56.33 abc	18.8 b-e
T_3F_1	13.80 ab	420.33 b-e	60.67 ab	15.33 e
T_3F_2	13.87 ab	485.33 a-d	51.33 abc	16.73 cde
T_4F_1	12.16 b	404.00 cde	58.67 ab	16.40 de
T_4F_2	12.28 b	470.67 a-d	55.17 abc	16.87 cde
T_5F_1	14.40 ab	563.67 a	62.67 ab	20.85 abc
T_5F_2	15.17 a	567.67 a	67.00 a	21.93 ab
T_6F_1	13.91 ab	491.67 a-d	51.67 abc	20.39 a-d
T_6F_2	13.81 ab	512.00 abc	48.67 bc	23.87 a
T_7F_1	14.00 ab	519.67 abc	63.00 ab	20.42 a-d
T_7F_2	14.49 ab	521.00 ab	64.33 ab	22.93 ab
CV (%)	**11.67**	**14.65**	**16.73**	**13.89**
LSD (0.05)	**2.66**	**116.55**	**15.88**	**4.44**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.12 Stover yield

Stover yield of sunflower was significantly influenced by the interaction of different micronutrients treatment with application method (Table 11). The highest stover yield (68.33 g plant^{-1}) was found from the foliar application of boron, manganese and zinc (T_7F_2) followed by foliar application of boron and zinc (T_5F_2) (63.67 g plant^{-1}). The lowest stover yield (39.0 g plant^{-1}) was obtained from soil application of manganese (T_2F_1), which was 75.21% lower than the maximum result. Both the seed yield and stalk yield of sunflower were increased with sulfur @ 40 kg ha^{-1} as soil application + Zn @ 0.5% + B 0.3% as foliar spray. By the foliar application of the previously cited doses of boron, zinc and sulfur the highest stalk yield (3312 kg ha^{-1}) was founded (Ravikumar *et al*., 2021). These results of combined application of foliar micronutrients supported the present research findings.

4.2.13 Biological Yield

From Table 11, it was observed that biological yield was significantly affected by the interaction effect of different levels of micronutrient and application method. Highest biological yield (113 g plant^{-1}) was found from the foliar application of boron, manganese and zinc (T_7F_2). The lowest biological yield (61.67 g plant^{-1}) was produced by the soil application of boron and manganese (T_4F_1). Manganese has an important role in increasing seed yield of soybean. Manganese plays a vital role on carbohydrates metabolism, synthesis of some proteins and nitrates, which increase seed yield (Wilson *et al*., 1982). Biological yield (g m^{-2}) of sunflower was influenced by the micronutrient treatment interaction of iron, manganese and zinc. In a previous experiment mixed application of iron, manganese and zinc showed the second-best biological yield (260.2 g m^{-2}) (Babaeian *et al.*, 2011).

4.2.14 Harvest Index

Effect of treatment interaction with application method doses exerted significant variation on harvest index (Table 11). Harvest index was highest (37.41%) in foliar application of boron, manganese and zinc (T_7F_2) followed by foliar application of boron and zinc (T_5F_2) (36.77%) and the lowest harvest index (20.20%) in soil application of zinc (T_3F_1). Harvest index (%) is the ratio of seed yield or economic yield and biological yield of a plant. Harvest index of sunflower was influenced by borax (B) and zinc sulphate (Zn) application in a previous study. The highest harvest index was found in application of boron spray as borax along with NPK, FYM imidacloprid seed treatment @ 5 g kg^{-1} seed (Halli *et al*., 2016). Mixed application of B and Zn had a similar result on harvest index.

Table 11. **Interaction effect of micronutrients and application method on stover yield, biological yield and harvest index of sunflower**

Treatment Interaction	Stover yield	Biological yield	Harvest index
T_1F_1	43.00 ef	69.00 c	22.48 bc
T_1F_2	47.00 def	69.33 c	31.52 abc
T_2F_1	39.00 f	64.00 c	25.68 abc
T_2F_2	52.00 b-f	87.33 abc	22.25 bc
T_3F_1	44.00 ef	76.00 bc	20.20 c
T_3F_2	39.33 f	69.67 c	22.72 bc
T_4F_1	50.41 c-f	61.67 c	29.32 abc
T_4F_2	53.53 b-e	74.33 bc	30.08 abc
T_5F_1	58.00 a-d	96.52 abc	34.08 ab
T_5F_2	63.67 ab	107.00 ab	36.77 a
T_6F_1	51.65 b-f	89.67 abc	29.56 abc
T_6F_2	62.00 abc	94.33 abc	36.46 a
T_7F_1	55.12 b-e	91.33 abc	36.238 a
T_7F_2	68.33 a	113.00 a	37.406 a
CV (%)	**15.10**	**25.11**	**24.20**
LSD (0.05)	**13.16**	**35.01**	**12.03**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

4.2.15 Oil percentage

Oil percentage was significantly influenced by the interaction of different micronutrient treatment with application method (Table 12). Foliar application of boron, manganese and zinc (T_7F_2) produced the highest oil (43.65%) and the lowest oil percentage (38.17%) found from the soil application of boron as a single micronutrient (T_1F_1). Sunflower oil content varied from one another in different genotypes. In a previous study about different genotypes the oil content varied from 23.69% to 36.46% (Sumon *et al.,* 2021). The highest amount of oil content was found (36.46%) to BARI Shurjomukhi-2. Analysis of variance of a pervious study showed that, interaction of iron, manganese and zinc had significant effect on oil percentage. According to interaction effect between $ZnSO_4$ and $FeSO_4$ the most oil percentage was in 40 kg h^{-1} $ZnSO_4$ consumption (Farokhi *et al.,* 2014). Zinc also plays an important role in the production of biomass, grain yield, quality and quantity of oil content (Maghsud S *et al.,* 2014) (Cakmak *et al.,* 2008). The present experiment findings are in agreement with the mentioned previous research results.

4.2.16 Seed moisture percentage

Seed moisture percentage of sunflower was significantly differed at different micronutrients with the variation of application methods (Table 12). The maximum seed moisture percentage (14.91%) was obtained from the soil application of boron, manganese and zinc (T_7F_1) and the minimum amount of seed moisture percentage (8.52%) revealed from the foliar application of manganese as a single dose micronutrient (T_2F_2). Sunflower seed moisture is important for storing the seed for a long period of time. Sunflower seeds can be safely stored usually at 10% moisture or less, but during warm weather moisture should be at 8% or less (Bax *et al.,* 2004; Myers, 2002). No previous research findings were found about the effect of micronutrients such as boron, manganese and zinc on seed moisture percentage of sunflower. In the present study, the seed moisture percentage varied from 8.52% to 14.91% in different treatment interaction. Seed moisture percentage of the present study is higher than the previously founded value form previous experiments. The moisture percentage of different sunflower genotypes was ranged from 4.78% to 6.29%. The highest value of moisture percentage was found in BARI Shurjomukhi-2 (6.29%), which was statistically similar to BARI Shurjomukhi-3 (5.85%) followed by Bangladeshi local (5.59%) variety (Sumon *et al.*, 2021).

4.2.17 Protein percentage

The protein percentage of seed moisture was significantly influenced by the interaction of different levels of micronutrient treatment along with application methods of the micronutrients (Table 12). The protein percentage ranged from 38.04 to 49.38%. Foliar application of manganese and zinc (T_6F_2) showed the highest protein percentage (49.38%) and the lowest protein percentage (38.04%) was observed from the soil application of boron as a single micronutrient (T_1F_1). Saad A. M. Al-Doori (2017) reported that protein percentage of sunflower influenced greatly by interaction effect of Zn and B. Boron foliar application @ 8 mg L^{-1} resulted the highest protein (15.47%).

Table 12. Interaction effect of micronutrients and application method on oil percentage, seed moisture percentage and protein percentage of sunflower

Treatment Interaction	Oil percentage	Seed moisture	Protein percentage
T_1F_1	38.17 i	13.45 c	38.04 g
T_1F_2	41.54 cde	10.25 h	40.16f g
T_2F_1	43.31 ab	12.12 f	44.12 cd
T_2F_2	41.85 cde	8.52 j	41.30 f
T_3F_1	43.24 ab	10.33 gh	42.57 def
T_3F_2	39.55 gh	12.83 de	46.77 b
T_4F_1	42.28 bcd	9.93 h	41.47 ef
T_4F_2	38.38 hi	10.72 g	43.87 de
T_5F_1	40.54 efg	8.76 j	46.56 bc
T_5F_2	41.33 def	9.25 i	40.92 f
T_6F_1	38.43 hi	13.26 cd	48.28 ab
T_6F_2	40.13 fg	14.26 b	49.38 a
T_7F_1	42.72 abc	14.91 a	48.10 ab
T_7F_2	43.65 a	12.57 ef	48.34 ab
CV (%)	**1.92**	**2.44**	**3.33**
LSD (0.05)	**1.33**	**0.47**	**2.47**

[Here, F_1=Soil application, F_2= Foliar application, T_1=B, T_2= Mn, T_3= Zn, T_4= B+ Mn, T_5= B+ Zn, T_6= Mn+ Zn, T_7= B+ Mn+ Zn. Mean was calculated from 3 replications from each treatment]

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the research field of Department of Agronomy, Sher-e-Bangla Agricultural University (SAU) during the period of November, 2020 to April 2021 to evaluate the influence of soil and foliar applied micronutrients (B, Mn, Zn) on sunflower for improving physiological traits, yield and oil content. The experiment consisted of micronutrient application method and micronutrient combination. The application methods were, F_1 = Soil application of micronutrient and F_2= Foliar application of micronutrient. The micronutrient combinations: T_1= Boron, T_2= Manganese, T_3= Zinc T_4= Boron+ Manganese T_5= Boron+ Zinc T_6= Manganese+ Zinc and T_7= Boron+ Manganese+ Zinc. The foliar micronutrient application rate was H_3BO_4= 0.5 g L^{-1} or @ 0.5%, $MnSO_4$= 1 g L^{-1} or @ 1% and $ZnSO_4$= 2 g L^{-1} or @ 2% and applied in three splits at 30 DAS, 50 DAS and 70 DAS. Micronutrients were applied, boron as boric acid (12 kg ha^{-1}), zinc as zinc sulphate (10 kg ha^{-1}) and manganese as manganese chloride (12 kg ha^{-1}) were applied during final land preparation. The recommended dose of N as Urea, P as TSP and K as MoP (180:150:120 kg ha^{-1}) were applied along with soil and foliar application of micronutrient. The experiment was laid out in a RCBD factorial design with three replications. Unit plot size was 2.25 m^2. Data of most of the growth parameters were measured three times, chlorophyll content was measured three times. Crop growth rate and relative growth rate was measured two times during the growth period. Yield contributing parameters were measured after harvesting. The data on plant growth characters like plant height, number of leaves $plant^{-1}$ and leaf area index were measured at 25,45 and 65 DAS. Total dry matter weight and relative water content were recorded at 25,50 and 75 DAS. Chlorophyll content was measured at 25, 45 and 65 DAS. Both crop growth rate and relative growth rate were recorded during 25 to 50 DAS and 50 to 75 DAS. Yield contributing characters like seed yield $plant^{-1}$, number of seed $plant^{-1}$, head diameter, stover yield, biological yield, harvest index, oil percentage, seed moisture percentage and protein percentage were recorded after harvest. All data of the mentioned parameters were analyzed by using STATISTIX-10 computer package.

Significant differences existed among different levels of micronutrient treatments with respect to crop growth characters like plant height, number of leaves plant^{-1}, leaf area index, total dry matter weight, relative water content, chlorophyll content, crop growth rate and relative growth rate. A significant variation in plant height at different plant ages was observed due to different micronutrient treatments. At 25 DAS, T_7 (B+ Mn+ Zn) showed the highest plant height (25.53 cm) and T_3 (Zn) showed the lowest plant height (20.46 cm). The difference between the lowest and highest plant height is 24.78%. T_7 also showed the best result both in 45 DAS (flowering stage) and 65 DAS (maturity stage). The combined treatment of boron, manganese and zinc (T_7) showed 82.67 cm and 145 cm height at 45 DAS and 65 DAS respectively. Plant height increased progressively during the growth stages until maturity. Significant variation was observed by different micronutrient treatments in number of leaf plant^{-1}. In all growth stages maximum leaf plant^{-1} were observed with T_7 (B+ Mn+ Zn). Combined treatment of boron, manganese and zinc (T_7) showed the best mean result at 25 DAS (6.83), 45 DAS (16) and 65 DAS (19.33). Regardless of treatment differences, leaf area index increased progressively until maturity stage. At 25 DAS, T_7 (B+ Mn+ Zn) showed highest LAI (0.20) and the lowest result (0.10) observed by solo application of boron (T_1). At both 45 DAS and 65 DAS T_5 (B+ Zn) revealed the highest performance, respectively 2.14 and 3.19. There was significant effect of treatment combination on leaf area index at all growth stages. Dry matter accumulation was highest at 50 DAS (5.82 g) but reduced at 75 DAS (2.35 g). Different levels of micronutrient treatments effectively influenced the DMW (Dry matter weight). Application of T_7 (B+ Mn+ Zn) produced highest dry matter weight (2.58 g) at 25 DAS, T_5 (B+ Zn) treatment influenced heavily by showing highest performance at 50 DAS (5.82 g) and 75 DAS (2.35 g). A significant difference was found in relative water content (RWC) from the application of different levels of treatment. At 25, 50 and 75 DAS the highest relative water content was found respectively from the application of T_5 (B+ Zn) (75.45%), T_7 (B+ Mn+ Zn) (72.37%) and T_7 (B+ Mn+ Zn) (71.38%). Treatment combination of boron, manganese and zinc (T_7) had positive role in increasing SPAD value at different growth stages of sunflower plant. T_6 (Mn+ Zn) at 25 DAS (39.03) and T_7 (B+ Mn+ Zn) at 45 DAS (40.6), and 65 DAS (38.79) showed the highest results. The result revealed that, both during 25-50 DAS (1.30 g day^{-1}m^{-2}) and during 50-75 DAS

(1.15 g $day^{-1}m^{-2}$) T_6 (Mn+ Zn) showed the highest crop growth rate (CGR) result. The crop growth rate declined at 50-75 DAS time period. It was observed that, Relative growth rate also showed similar trend. T_5 (B+ Zn) showed best mean performance both during 25-50 DAS (0.08 g g^{-1} day^{-1}) and during 50-75 DAS (0.05 g g^{-1} day^{-1}).

Effect of different levels of micronutrient treatments exhibited significant variation in all the studied yield contributing characters. Application of T_5 (B+ Zn) performed best head diameter (14.78 cm) and T_4 (B+ Mn) had the lowest mean (12.22 cm). Significant difference was observed in 1000 seed weight due to different levels of micronutrient treatments. The highest performance found from the application of T_5 (B+ Zn) (64.83 g) followed by T_7 (B+ Mn+ Zn) (63.67 g) treatment combinations. The lowest thousand seed weight (46.83 g) observed by the solo application of boron (T_1). Sunflower seeds $head^{-1}$ also showed significant influence on treatment combinations. T_5 (B+ Zn) revealed the highest seed $head^{-1}$ (565.67) and the solo application of boron (T_1) showed the lowest (357.17) seed count. Highest seed yield $plant^{-1}$ (22.13 g) revealed from T_6 (Mn+ Zn) treatment and the lowest one from T_3 (Zn) treatment (16.03 g). Combined application of boron, manganese and zinc (T_7) produced highest stover yield (61.73 g) and biological yield (102.17 g). T_5 (B+ Zn) showed the 2^{nd} highest biological yield (101.76 g). Maximum harvest index (%) was observed from the application of T_7 (B+ Mn +Zn) (36.82%) and the lowest one obtained from the solo application of zinc (T_3) (21.46%) Significantly the highest Seed moisture percentage was observed with T_6 (Mn+ Zn) (13.76%) and the lowest with T_5 (B+ Zn) (9.0%).

Significant variation in oil percentage was observed with T_7 (B+ Mn+ Zn) (43.18%). The lowest oil percentage observed from the treatment combination of manganese and zinc (T_5) (39.28%). There was a significant difference observed due to different levels of micronutrient treatments. Highest protein percentage (48.83%) found from the application of T_6 (Mn+ Zn) and the lowest one found from solo application of boron (T_1) (39.10%).

Effect of micronutrient application method was observed significantly both in growth parameters and yield components in this experiment. F_2 (foliar application) showed better plant height at 25 DAS (22.65 cm), 45 DAS (73.83 cm) and 65 DAS (134.02 cm) than the F_1 (soil application). The average plant height from F_1 (soil application) resulted 22.22 cm, 67.29 cm and 126.09 cm respectively at 25 DAS, 45 DAS and 65 DAS. Number of leaf plant^{-1} affected significantly by the application method of micronutrients. F_2 (foliar application) showed slightly better result at 25 DAS (6.38), 45 DAS (14.48) than the soil application of micronutrients (F_1). At 65 DAS F_1 (soil application) showed better performance (18.09) than F_2 (foliar application) (17.76). Leaf area index increased with age reaching a peak at 65 DAS. There was no significant difference revealed from the 2 application methods. At 25 DAS higher LAI observed from F_1 (soil application) (0.143). At 45 DAS (1.70) and 65 DAS (2.61) higher LAI found from F_2 (foliar application). Result indicated that, no significant variation observed from the micronutrient application method in DMW (dry matter weight) accumulation in this experiment. F_1 (soil application) gave higher DMW at 25 DAS (2.21 g), 75 DAS (2.03 g) than F_2 (foliar application) (2.13 g) and (1.85 g). At 50 DAS F_2 (foliar application) showed better result (5.06 g) than F_1 (soil application) (4.88 g). There was no significant difference observed in RWC (Relative water content) performance from the two different micronutrient application methods. At all the growth stages F_2 (foliar application) produced numerically better result than F_1 (soil application). At 25 DAS (72.38%), 50 DAS (68.76%) and 75 DAS (67.81%) numerically higher relative water content obtained from F_2 (foliar application). In terms of SPAD value there was no significant effect revealed from the two different application methods of micronutrient treatment. At all the growth stages numerically higher SPAD value observed from the F_1 (soil application). At 25 DAS (37.19), 45 DAS (38.13) and 65 DAS (38.04) numerically better chlorophyll content obtained from F_1 (soil application). Same phenomenon revealed in CGR (Crop growth rate) also. F_1 (soil application) showed numerically higher CGR than the F_2 (foliar application) during both 25-50 DAS and during 50-75 DAS. There was no significant variation found on RGR (Relative growth rate) with different micronutrient application methods. During 25-50 DAS same RWC (0.05%) observed from both F_1 (soil application) and F_2 (foliar application).

By observing the data of yield contributing parameters it was revealed that F_2 (foliar application) resulted slightly better performance in most of the parameters like head diameter (13.7 cm), seed plant^{-1} (495), seed yield (20.37 g), stover yield (55.12 g), biological yield (87.86 g), harvest index (31.03%) and protein percentage (44.39%) than the soil application of micronutrients (F_1). Meanwhile, F_1 (soil application) gave higher performance in thousand-gram seed weight (58.09 g), oil percentage (41.24%) and seed moisture percentage (11.82%). There was no statistically significant difference among most of the yield contributing characters.

Interaction effect of different micronutrients and application method significantly influenced the studied crop growth characters during the plant growth stages. It was observed, T_7F_1 (soil application of B+ Mn+ Zn) showed tallest plant height at 25 DAS (26.50 cm) and 65 DAS (144.94 cm). T_7F_2 (foliar application of B+ Mn+ Zn) showed highest plant height performance (84.61 cm) at 45 DAS. Solo application of boron in soil (T_1F_1) gave the lowest plant height at 45 (49.28 cm) and 65 DAS (103.46 cm). Similar trends also observed in number of leaf plant^{-1}. T_7F_1 (soil application of B+ Mn+ Zn) gave the highest number of leaves plant^{-1} at 25 DAS (7.33) and 65 DAS (20.33). Application of T_5F_2 (foliar application of B+ Zn) resulted highest leaves at 45 DAS (16.67). A significant variation in leaf area index (LAI) at different plant ages was observed due to interaction of micronutrient treatments and application method. LAI increased over time attaining. T_5F_2 (foliar application of B+ Zn) showed positive significance in LAI. At 45 DAS (2.55) and 65 DAS (3.20) T_5F_2 (foliar application of B+ Zn) showed highest leaf area index. At 25 DAS highest LAI (0.26) obtained with soil application of boron, manganese and zinc (T_7F_1). Dry matter weight was increased progressively during the vegetative growth stage but decreased before harvesting time period. T_7F_1 (soil application of B+ Mn+ Zn), T_5F_2 (foliar application of B+Zn) and T_7F_2 (foliar application of B+ Mn+ Zn) resulted the highest DMW at 25 (2.69 gm), 50 (6.17 g) and 75 DAS (2.37 gm) respectively during the experiment. At all growth stages relative water content was influenced significantly due to the interaction effect of treatments and application method. At 25 (76.10%), 50 (72.88%) and 75 DAS (71.72%) highest RWC was revealed with T_5F_1 (soil application of B+ Zn), T_7F_2 (foliar application of B+ Mn+ Zn) and T_5F_2

(Foliar application of B+ Zn) respectively. Interaction of treatments with application method had positive role in chlorophyll content. At 25 DAS (39.42), 45 DAS (40.88) and 65 DAS (39.73) the highest SPAD value obtained with T_6F_1 (soil application of Mn+ Zn), T_7F_1 (soil application of B+ Mn+ Zn) and T_7F_2 (foliar application of B+ Mn+ Zn) respectively. Application of T_6F_1 (Soil application of Mn+ Zn) produced the highest CGR both during 25-50 DAS (1.61 g day^{-1} m^{-2}) and 50-75 DAS (1.33 g day^{-1} m^{-2}). T_5F_2 (foliar application of B+ Zn) showed the highest RGR (Relative growth rate) during 25-50 DAS (0.09 g g^{-1}day^{-1}) and 50-75 DAS (0.06 g g^{-1}day^{-1}).

Interaction of micronutrients with the application method showed significant variation on all the studied yield components of sunflower during the present experiment. T_7F_2 (foliar application of B+ Mn+ Zn) showed the best result in stover yield (68.33 g), biological yield (113 g), Harvest index (37.41%) and oil percentage (43.65%). The best seed yield (23.87 g) and protein percentage (49.38%) were obtained with T_6F_2 (foliar application of Mn+ Zn). T_5F_2 (foliar application of B + Zn) showed the best results on head diameter (15.17 cm) 1000 seed weight (67 g) and seed plant^{-1} (567.67).

CONCLUSION

From the results of the present research experiment, it could be concluded that, T_7 (B+ Mn+ Zn) and T_5 (B+ Zn) micronutrient treatment showed superiority in most of the studied crop growth parameters. In yield and yield attributing characters, combination of more than one micronutrient showed the best result. Application of T_7 (B+ Mn+ Zn), T_5 (B+ Zn) and T_6 (Mn+ Zn) gave the highest yield components. Application method of micronutrients revealed a mixed result in the present experiment. There was no significant difference found between soil application (F_1) and foliar application (F_2) in most of the studied parameters. In some parameters F_1 (soil application) showed numerically higher results and in some parameters F_2 (foliar application) showed comparatively better performance. In most of the yield attributing characters F_2 (foliar application) showed better results than F_1 (soil application). Interaction of different micronutrient treatments and application method showed a mixed result in the growth parameters in this study. In yield attributing characters like stover yield, biological yield, harvest index, oil percentage, T_7F_2 (foliar application of B+ Mn+ Zn) showed the best result. Highest seed yield and protein percentage was obtained with the foliar application of manganese and zinc (T_6F_2). Foliar application of boron and zinc (T_5F_2) showed best performance in thousand seed weight, head diameter and seed plant^{-1}. However, to reach a specific conclusion more research work on different micronutrient treatments should be done to get more efficient result.

RECOMMENDATION

Considering results of the present experiment, further studies in the following areas are suggested.

1. Different types of micronutrient combination may be used for better performance in growth and yield attributing traits.

2. Studies of similar nature could be carried out in different agroecological zones (AEZ) of Bangladesh for the evaluation of zonal adaptability

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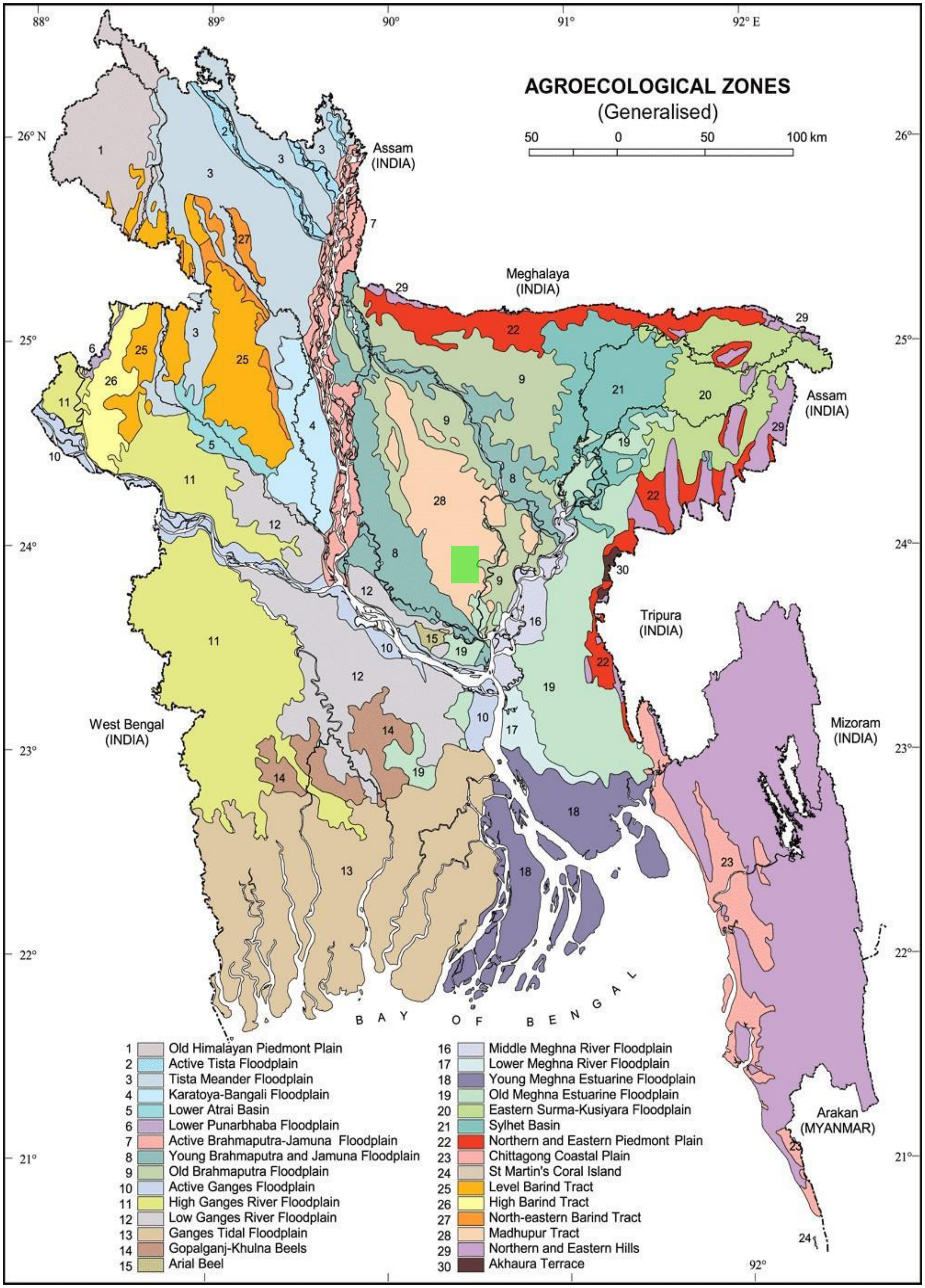
APPENDICES

Appendix I. Map showing the experimental site under study



N B. The green colored mark indicates the experimental site under study.

Appendix II. Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Boro-Aman-Boro

B. Physical and chemical properties of the initial soil before seed sowing

Characteristics	**Value**
% Sand	27
% Silt	43
% Clay	30
Textural Class	Silty-clay
pH.	6.7
Organic carbon (%)	0.45
Organic matter (%)	2.64
Total N (%)	0.15
Available P (ppm)	22.60
Exchangeable K (meq/ 100 gm soil	0.18
Available Boron (ppm)	3.96
Available Manganese (ppm)	83.26
Available Zinc (ppm)	28.56

Source: SRDI, 2020, Lab no: 3636

Appendix III. Monthly record of air temperature, relative humidity, rainfall, and sunshine hour of the experimental site during the period of November 2020 to March 2021

Year	Month	Temperature			Relative Humidity (%)	Rainfall (mm)	Sunshine (Hour)
		Max C	Min C	Mean C			
2020	November	30.7	20.1	25.5	69	40	6.3
	December	25.0	16.0	21.0	73	00	5.7
2021	January	25.5	14.8	20.2	72	00	6.7
	February	29.5	16.9	23.3	60	00	8.2
	March	34.4	23.1	28.8	57	03	8.1

Source: Yearbook of Agricultural Statistics- 2021

Appendix IV. Means square values for plant height (cm) of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing		
		25 DAS	45 DAS	65 DAS
Replication	2	46.78	440.03	198.80
Treatment combination (T)	6	1.92	465.05	820.51
Application method (F)	1	26.09	448.38	659.42
T × F	6	9.90	60.95	99.99
Error	26	11.92	154.34	155.46

Appendix V. Means square values for leaf plant^{-1} of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing		
		25 DAS	45 DAS	65 DAS
Replication	2	1.809	440.029	198.795
Treatment combination (T)	6	0.801	465.046	820.507
Application method (F)	1	0.214	448.383	659.419
T × F	6	1.770	60.948	99.994
Error	26	0.527	154.344	155.458

Appendix VI. Means square values for Leaf area index of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing		
		25 DAS	45 DAS	65 DAS
Replication	2	0.01109	1.63195	1.33721
Treatment combination (T)	6	0.00795	1.30163	1.20336
Application method (F)	1	0.00022	1.91304	0.51924
T × F	6	0.00690	0.08712	0.12087
Error	26	0.00297	0.22284	0.32322

Appendix VII. Means square values for Chlorophyll content of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing			
		25 DAS	45 DAS	65 DAS	85 DAS
Replication	2	0.180	6.959	4.264	8.442
Treatment combination (T)	6	5.647	17.222	5.288	9.095
Application method (F)	1	16.176	6.295	7.595	0.489
T × F	6	2.369	2.182	4.081	14.041
Error	26	2.270	3.086	3.093	5.354

Appendix VIII. Means square values for relative water content (%) of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing		
		25 DAS	50 DAS	75 DAS
Replication	2	9.753	19.645	26.362
Treatment combination (T)	6	41.367	54.698	44.152
Application method (F)	1	7.845	15.241	13.817
T × F	6	9.224	18.990	22.650
Error	26	18.878	13.387	19.499

Appendix IX. Means square values for total dry matter production (g) of sunflower at different days after seed sowing

Sources of variation	Degrees of freedom	Means squares values at different days after seed sowing		
		25 DAS	50 DAS	75 DAS
Replication	2	0.262	0.812	0.054
Treatment combination (T)	6	0.409	1.862	0.872
Application method (F)	1	0.066	0.362	0.321
T × F	6	0.129	0.531	0.257
Error	26	0.238	0.944	0.481

Appendix X. Means square values for crop growth rate (g day^{-1} m^{-2}) and relative growth rate (g g^{-1} day^{-1}) of sunflower at different time periods

Sources of variation	Degrees of freedom	CGR (25-50 DAS)	CGR (50-75 DAS)	RGR (25-50) DAS	RGR (50-75) DAS
Replication	2	0.019	0.475	1.357E-04	1.126E-04
Treatment combination (T)	6	0.925	0.666	1.927E-03	9.325E-04
Application method (F)	1	0.239	0.031	1.881E-34	9.054E-04
T × F	6	0.207	0.101	6.556E-04	1.903E-04
Error	26	0.005	0.225	4.793E-04	7.980E-05

Appendix XI. Means square values for floral head diameter, Number of seeds head^{-1}, thousand seed weight, seed yield of sunflower

Sources of variation	Degrees of freedom	Head diameter (cm)	Seed plant^{-1}(No.)	1000 seed weight (g)	Seed yield (g)
Replication	2	1.605	4074.6	255.668	12.263
Treatment Combination (T)	6	5.200	26839.0	256.065	40.166
Application method (F)	1	0.448	19457.5	95.734	72.076
T×F	6	0.187	1804.7	35.373	6.407
Error	26	2.515	4822.3	89.559	7.014

Appendix XII. Means square values for stover yield, biological yield, harvest index (%) of sunflower

Sources of variation	Degrees of freedom	Stover yield (g plant^{-1})	Biological yield (g plant^{-1})	Harvest index (%)
Replication	2	148.740	477.27	165.542
Treatment Combination (T)	6	393.913	1373.75	202.579
Application method (F)	1	427.907	956.58	82.758
T×F	6	61.272	177.11	25.338
Error	26	61.512	435.33	51.409

Appendix XIII. Means square values for oil percentage, seed moisture percentage and protein percentage of sunflower

Sources of variation	Degrees of freedom	Oil percentage (%)	Seed moisture percentage (%)	Protein percentage (%)
Replication	2	0.85	0.05	4.36
Treatment Combination (T)	6	12.08	19.28	68.52
Application method (F)	1	1.09	4.04	0.55
T×F	6	11.49	8.53	17.14
Error	26	0.62	0.08	2.17