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Uptake of Sodium and Lithium in *Oryza sativa* L. Cv. Super Kainat Exposed to Different Concentrations of NaCl and LiCl

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Abstract | **Original Research Article**

In the present study, *Oryza sativa* L. cv. Super Kainat was grown in pots and treated with different concentration of NaCl i.e., 15, 30, 45, 60 mM L^{-1}, and LiCl i.e. 1, 2, 3 and 4 ppm. The main purpose of this study was to investigate the effect of NaCl and LiCl stress on *Oryza stiva* L.cv. super kainat for its growth, yield and physiological parameters i.e., rate of transpiration and photosynthesis and stomatal conductance, which were measured by using infrared gas analyzer. The fresh and dry weight was also measured after harvesting by weighing balance. After exposure to NaCl and LiCl concentrations, the number of leaves and plant height were monitored on weekly basis. There were four treatments T0, T1, T2, T3, T4 and each consisted of five replicates. After four weeks of sodium and Lithium application the length of plant and number of leaves were reduced significantly as compared to control. Na^+ Li^+ and K^+ uptake in roots, shoots, leaves and grains were analyzed by using flame photometer. The maximum level of Na^+ uptake was found in shoot of T3. The amount of Na^+ uptake in grains was found to be minimal than in roots, shoots and leaves. The Na^+ uptake in roots was found minimum in T0 and T4. Lithium uptake was maximum in the shoot of studied cultivar. Lithium uptake in grains and roots was minimum. The K^+ uptake was found maximum in shoots. T4 had minimum uptake of K^+. The present study concludes that the rice plant cultivar Super Kainat could tolerate the NaCl up to 60 mM L^{-1} salt stress and LiCl upto 4 ppm concentration. This can help in its cultivation in different saline areas.

Keywords: Rice, NaCl, LiCl, Ion Uptake, Super Kainat, Salinity Stress.

INTRODUCTION

The study of ion uptake in plants, particularly in economically significant crops like rice, has been an area of intense research due to its implications on growth, development, and stress tolerance (Smith *et al.,* 2015). Osmoregulation, enzyme activation, and membrane potential are only a few of the numerous physiological processes dependent on essential ions such as sodium (Na), lithium (Li), and potassium (K) (Jones and Wang, 2010). Recently, "Super Kainat" rice has been in the limelight due to its ability to assimilate abnormally large quantities of specific ions. The assimilation of Na, Li, and K at the tissue level could provide insight into this variety's potential for cultivation in a wide range of soil conditions, including those with varying concentrations of sodium chloride (NaCl), lithium chloride (LiCl), and potassium chloride (KCl). High concentrations of sodium chloride (NaCl) are toxic to plants, resulting in salinity stress (Munns and Tester, 2008). Whether or not "Super Kainat" can develop in salty environments is contingent on its capacity to absorb and retain sodium (Khan *et al.,* 2019).

Lithium is beneficial for research despite the fact that plants do not require it because it competes with potassium for uptake in the soil (Rodriguez-Navarro and Rubio, 2006). How "Super Kainat" responds to LiCl exposure may reveal information about its K transport systems and potential resistance to Li toxicity. Due to the importance of potassium to plant growth and development, lot of research done on how various plant species ingest and transport potassium (Wang *et al.,* 2013). Understanding how "Super Kainat" reacts to KCl should aid in optimizing its growth, although the fundamental mechanisms have not yet been studied.

Plants rely on the absorption of various ions to regulate a variety of physiological processes, including food assimilation, osmoregulation, and signal transduction (Marschner, 2011). Through the selective absorption of ions, plants are able to attain and maintain internal homeostasis, which is essential for healthy development and growth (Taiz *et al.,* 2015). How efficiently a plant absorbs these ions can affect its resistance to salinity, drought, and nutrient deprivation (Munns and Tester, 2008). Sodium, lithium, and potassium are required for several crucial physiological processes in plants. Each of these factors has numerous effects on growth, development and health of plants.

Sodium is required by plants for two distinct functions. Some halophytic plant species require it, and it's also beneficial in situations where potassium is utilized (Flowers *et al.,* 2010). Sodium contributes to osmotic equilibrium and is beneficial at low concentrations, but toxic at high concentrations, resulting in salinity stress (Munns & Tester, 2008). Sodium is a vital nutrient, despite the fact that plants require much less of it than they do of other elements. Despite its lower soil concentration, sodium serves an essential role in plant physiology. (Marschner, 2012) Osmotic control, in which sodium ions participate, is essential for the maintenance of cellular water balance in plants. Sodium also facilitates the transport of other nutrients across cell membranes. Some plants, specifically halophytes, have evolved mechanisms to store sodium in their tissues in order to persist in salty environments (Flowers & Colmer, 2008).

Lithium is not considered an essential element because its physiological function in vegetation is unknown. Lithium is typically found in trace quantities in soils and has a negligible effect on plant growth and development. Unlike sodium and potassium, lithium does not play a major function in ion transport or cellular processes in plants. Due to lithium's negligible impact on plant physiology, little research has been conducted into its mechanism of action. Lithium has been utilized in the study of cation transport mechanisms despite the fact that it is not required for plant growth (Rodriguez-Navarro & Rubio, 2006). Since lithium and potassium compete for assimilation, understanding lithium can shed light on the transport and regulation of essential cations (Jensen *et al.,* 2010). Potassium is an essential macronutrient for plants due to its function in numerous physiological processes, such as the activation of enzymes, the opening and closing of stomata, and the maintenance of membrane potential (Wang *et al.,* 2013). The growth, development, and stress response of plants all depend on its absorption and transport. Potassium is an essential macronutrient for plants because it is involved in a variety of processes that are essential to their growth and survival. Potassium ions regulate the water transport (osmosis) within cells and tissues. Maintaining turgor pressure, which helps prevent cell collapse, is crucial (Leigh &Wyn Jones, 1984).

There may be distinguishing qualities of the "Super Kainat" rice variety. Examples include growth rate, grain quality, disease resistance, and environmental adaptation. The significance of these traits may reside in their adaptability to harsh environments, nutritional value, or agricultural output. A summary of studies investigating the genetic makeup, physiological responses, and potential applications of the "Super Kainat" type. This ranges from investigations into its unique molecular characteristics to inquiries into how it responds to various stimuli. This summary provides a comprehensive understanding of what is known about this species and highlights areas requiring further research.

Sodium (Na) is unique in plant biology because it can have both positive and negative effects. Some halophytic plants require micronutrient sodium for osmotic equilibrium and metabolism (Flowers *et al.,* 2010). Sodium is not required for plant growth and can be toxic in high quantities. Excessive sodium uptake has been linked to cell damage, disruption of potassium uptake, and other cellular activities (Munns and Tester, 2008). The symptoms of sodium poisoning include leaf necrosis, stunted growth, and decreased yield (Maathuis, 2014). Salinity stress, which is caused by excessive levels of sodium chloride (NaCl) in the soil, threatens global crop yield (Munns & Tester, 2008). Plants can experience osmotic stress due to dehydration and ionic stress due to an excess of detrimental sodium ions in salty environments (Munn & Gilliham, 2015).

Sodium is a vital nutrient, despite the fact that plants require much less of it than they do of other elements. Despite its lower soil concentration, sodium serves an essential role in plant physiology. (Marschner, 2012) Osmotic control, in which sodium ions participate, is essential for the maintenance of cellular water balance in plants. Sodium also facilitates the transport of other nutrients across cell membranes. Some plants, specifically halophytes, have evolved mechanisms to store sodium in their tissues in order to persist in salty environments (Flowers & Colmer, 2008). Numerous plant adaptations allow them to persist in environments with high salt concentrations. Among these mechanisms are the prevention of sodium absorption, the storage of sodium in vacuoles, and the production of suitable solutes to relieve osmotic stress (Zhu, 2001). As a means of controlling sodium homeostasis, increased expression of sodium transporters, including the SOS1 antiporter, has been observed in several plants (Shi *et al.,* 2002). If we are to create salt-tolerant varieties and improve farming techniques in salty regions, we must have a better comprehension of how plants absorb sodium and respond to salinity stress (Roy *et al.,* 2014).

Lithium (Li) is not essential for plant growth, but researchers have used Li absorption and transport as a model to investigate cation transport pathways. Since lithium shares chemical and structural similarities with

potassium (K), it can compete with K for uptake, revealing information about the selectivity and operation of potassium transporters (Rodriguez-Nava & Rubio, 2006). Lithium has been utilized in research to elucidate the role of certain transporters, including HKT and KUP family members, in maintaining cation homeostasis (Gierth & Maser, 2007). Lithium has also been used to investigate cation stress response signaling pathways (Jensen *et al.,* 2010). Lithium can be harmful to plants despite its utility as a research instrument. Inhibition of root growth, necrosis of the leaf tips, and reduced blossoming are all symptoms of lithium poisoning (Raven, 1980). It is believed that lithium disrupts potassium uptake and enzymatic activities (Gupta *et al.,* 2012), although the precise causes of lithium toxicity are still being investigated.

Lithium is not considered an essential element because its physiological function in vegetation is unknown. Lithium is typically found in trace quantities in soils and has a negligible effect on plant growth and development. Unlike sodium and potassium, lithium does not play a major function in ion transport or cellular processes in plants. Due to lithium's negligible impact on plant physiology, little research has been conducted into its mechanism of action. As a means of contending with lithium toxicity, plants limit lithium uptake, sequester lithium in specific cellular compartments, and activate stress response pathways. To increase plant tolerance to other harmful ions, it is necessary to gain a deeper understanding of these resilience mechanisms (Gupta *et al.,* 2012). Lithium assimilation and its effects on plants shed light on cation transport processes and stress responses. It may also be applicable in other contexts, such as environmental stress resistance research.

Potassium (K) is an essential macronutrient for plant growth and development, and it also plays a crucial role in a wide variety of other physiological processes. It is essential for maintaining membrane potential, regulating stomatal opening and closing, stimulating enzyme activity, and facilitating nutrient transfer (Wang *et al.,* 2013). Due to its function in protein synthesis, glucose metabolism, and stress responses, potassium is crucial for plant growth and development (Leigh & Wyn Jones, 1984). Potassium deficiency has been linked to reduced growth, diminished root development, and increased susceptibility to disease and environmental stresses (Marschner, 2011). Potassium, on the other hand, increases crop yield and quality, reduces pest and disease susceptibility, and enhances water efficiency (Cakmak, 2005). Potassium ion absorption, translocation, and homeostasis in plants are governed by numerous transporters and channels (Very & Sentenac, 2003). Depending on the exogenous potassium concentration, potassium uptake from the soil is mediated by high-affinity and low-affinity transport systems (Gierth & Maser, 2007). Potassium is also essential for several metabolic processes in plants, including the activation of enzymes and the synthesis of proteins. It effects stomatal opening and closing to further regulate gas exchange and transpiration (Maathuis, 2014). Potassium's role in nutrient uptake and transport influences the movement of other ions and nutrients throughout the plant (Hafke *et al.,* 2005). Potassium can fortify cell membranes and boost plant vitality, both of which have been associated with enhanced disease resistance (Huber & Jones, 2013). Potassium also facilitates the body's ability to generate and store energy, which is essential for growth and reproduction.

Potassium uptake at high concentrations is mediated by low-affinity transporters of the KUP/HAK family (Gupta *et al.,* 2008). Specialized channels, such as those belonging to the Shaker family (Dreyer & Uozumi, 2011), distribute potassium throughout the plant at optimal levels for healthy growth and development. Optimizing plant growth and agricultural output necessitates a comprehensive understanding of potassium's role in plant development and its transport mechanisms. In addition, it provides the groundwork for research into methods to improve crop resilience and yield under a broad range of climatic conditions.

3. MATERIAL AND METHODS

3.1 Materials

3.1.1. Chemical and Reagents

- Sodium Chloride
- Lithium Chloride
- Potassium Chloride
- Nitric acid
- Distilled Water

3.1.2 Apparatus and Glassware

- Beakers
- Aluminum foil
- Cotton roll
- Stirrer
- Funnel
- Flasks
- Whatman filter paper
- Crucibles
- Plastic bottles
- Tissue roll
- Pipette

3.1.3 Laboratory Equipment

- Infra-Red Gas Analyzer
- Portable Chlorophyll meter
- Weighing Balance
- Oven
- Muffle France
- Flame Photometer

3.2 Experimental Site

The Government College University's Botanical Garden, which is close to the Lahore Zoo on Mall Road, was the site of this investigation. With a

seven-acre plot of ground, it has the distinction of being Pakistan's first botanic garden. Since 1912, the Government College University Department of Botany has been in charge of maintaining this garden. The typical temperature range for the summer is 34°C to 37°C, while the typical range for the winter is 25°C to 27°C. The soil in the garden contains clay and silt particles, creating an environment that is favorable for plant growth. The hue of the soil itself is dark brown.

3.2.1 Experimental Setup

10 earthen pots with a diameter of 14 inches were used in this study. Both the designated treatment and the number of replications were written on each container. Each pot included 5 kg of garden soil inside of it. The plants were subjected to salt stress after a four-month period of acclimatization to their containers. For NaCl, the four salt treatments T1, T2, T3, and T4 were used. This also applied to LiCl. When T0 was in charge. There were four distinct sodium chloride concentrations used 15 mM, 30 mM, 45 mM, and 60 mM while one served as the control. There were four Lithium chloride concentrations used (1, 2, 3 and 4 ppm) while one served as the control. A total of 10 pots were utilized for the experiment having 5 rice plants transferred to each.

Table 3.3: Showing various NaCl and LiCl concentrations applied to *Oryza sativa* L. cv. Super Kainat:

Treatment	NaCl Concentration mg/kg	LiCl Concentration mg/kg
To	0	0
T1	877	42.39
T2	1755	84.78
T3	2632	127.17
T4	3510	169.5

3.4 Growth Assessment:

3.4.1 Measurement of Length of Plant (CM)

The measurement or height of plant were taken accurately, when plants were at maximum growth stage. Manual counting was used to count the leaves. Tillers were used to measure plant height, and panicles grew at the tips of the tillers. A centimeter scale or measuring tape was placed from the base of the shoot to the rice plant's longest leaf in order to gauge plant length. Every height measurement was documented.

3.4.2 Measurement of Number of Leaves

Leaf counts were taken both before and after the application of NaCl and LiCl and the recorded observations included the number of leaves in each case.

3.5 Physiological Assessment

For each treatment, different physiological parameters of plant leaves were evaluated using an infrared gas analyzer (IRGA-LCA-4). These criteria included:

- Rate of Transpiration (mmol m^{-2} s-1)
- Rate of Photosynthesis (mol m^{-2} s-1)
- (mmol m^{-2} s-1) Stomatal Conductance

The IRGA's operational chamber was used to measure the net photosynthetic rate (A), transpiration rate (E), and gaseous exchange rate (gs) for each *Oryza sativa* treatment using mature, healthy leaves. After organizing the data, the Sigma Plot program was used to calculate the mean and standard error.

3.6 Biomass Assessment

After grain formation, plants were harvested when they were mature. Fresh weight was ascertained using a weighing balance. Then the above- and below-ground components were divided. The plants were removed from each pot and dried at 65°C for 72 hours before the dry mass of the sections above and below the ground was estimated.

3.7 Determination of Na^+, Li^+ and K^+ Uptake

One gram (1g) of root, shoot, and grain was obtained from each replicate of each treatment using a weighing scale. All samples totaling one gram were heated for two hours in a muffle furnace at roughly 450°C. Take 1g of root, shoots, leaves, and grains from duplicates of each treatment (T0, T1, T2, T3, T4) for sample preparation. For further processing, 1g of the samples from each treatment were put into crucibles. The sample preparation was done in 30ml-sized crucibles. Using a lead pencil, mark all the samples as T0, T1, T2, T3, and T4. For example, the root, shoot, and grain sample of T0 was marked T0r, T0s, T0g, and the root, shoot, and grain sample of T1 was marked T1r, T1s, T1g. identical labeling was done for other treatment as well.

3.8 Preparation of 0.01 N HNO3 Solution

In a measuring flask of 1000 mL, 0.45 mL of HNO3 was added into the flask. To raise the final volume up to 1000 mL, more distilled water was then added into the flask.

3.8.1 Preparation of Stock Solutions

NaCl standard solutions with concentrations of 60 ppm and 100 ppm were created and kept in reagent bottles in order to measure the concentration of sodium (Na^+). Similar to this, stock solutions of KCl and LiCl, with concentrations of 60 ppm and 100 ppm respectively, were produced for the measurement of potassium (K^+) and lithium (Li^+). The ash was then mixed with 30 mL of a 0.01 N solution of HNO3, generating a suspension. The filtrate from this suspension was then transferred to a 100

mL measuring flask after being filtered with Whatman's filter paper number 42. The flask's volume was raised to 100 mL by the addition of distilled water. The sample flasks were then kept in a cool, dark location for later Na^+ and K^+ examination. He levels of Na^+ and K^+ were measured using a flame photometer (S20 Spectro lab model: 405). The flame photometer's results were meticulously recorded, and the data's mean and standard error were computed. With the use of a Flame photometer (S20 Spectro lab model: 405), the Na and K content was determined.

3.9 Statistical Analysis

Statistical analyses were performed after data on plant biomass, plant growth, sodium and potassium levels, as well as physiological and morphological parameters recorded during the study, were compiled. All replicates' average and standard error were calculated, and then they were compared to the control group using a t-test.

4. RESULTS

4.1. Length of Oryza Sativa L.cv. Super Kainat after Salt Treatment (NaCl):

The length of plants of Sodium during 1st week after salt treatment was ranged from 35cm to 45cm in T4 to T0 respectively. The treatments T1, T2, T4, were showing significant difference with T0 (control) while treatment T3 was showing nonsignificant difference with T0 (control). During week 2^n week the length of plant ranged from 36cm to 38cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control) group.

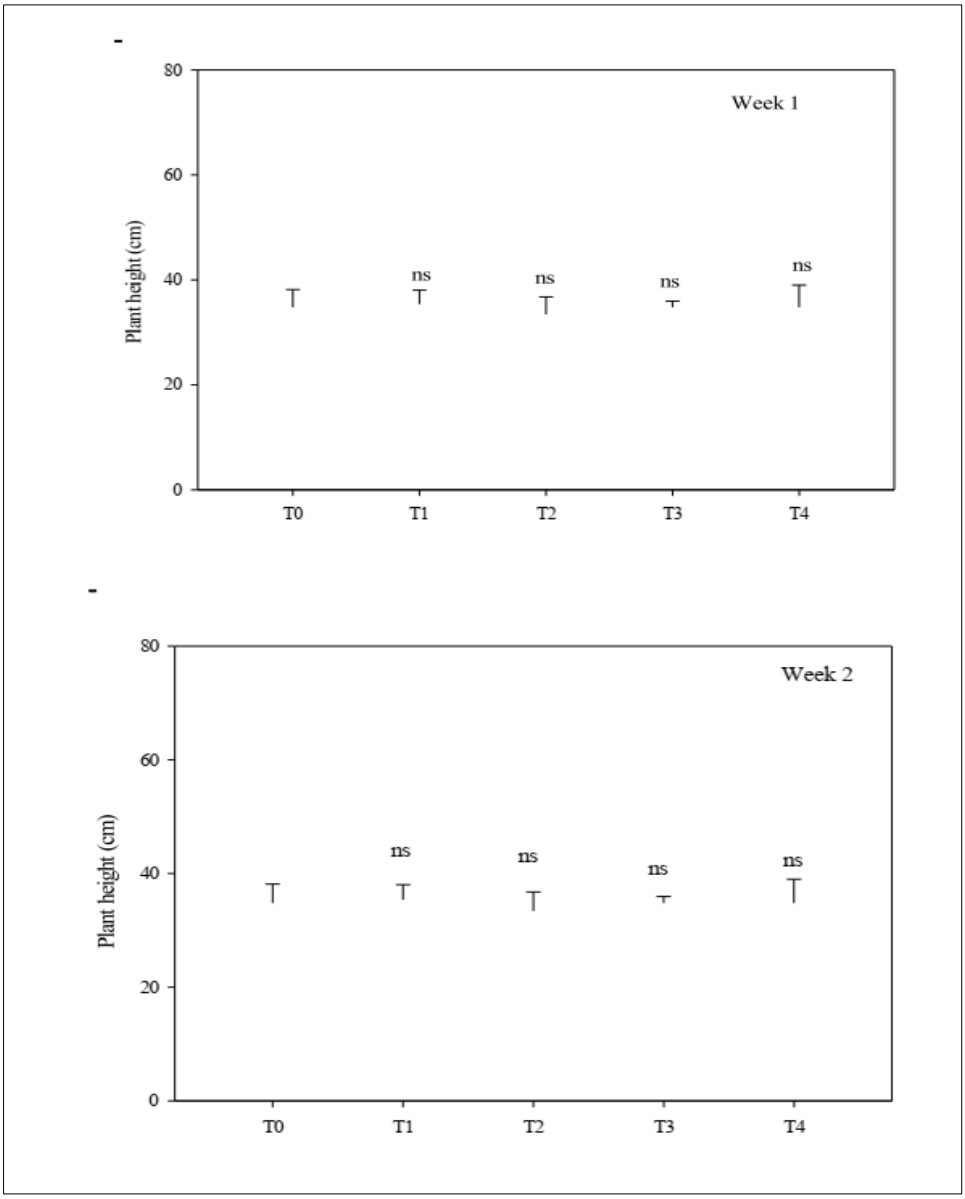


Figure 4.1: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 1sth week, and during 2nd week

The length of plants during 3rd week after salt treatment was ranged from 30cm to 39cm in T4 to T0 respectively. The treatments T1, T2, T4, were showing significant difference with T0 (control) while treatment T3 was showing significant difference with T0 (control). During week 4th week the length of plant ranged from 38cm to 45cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control).

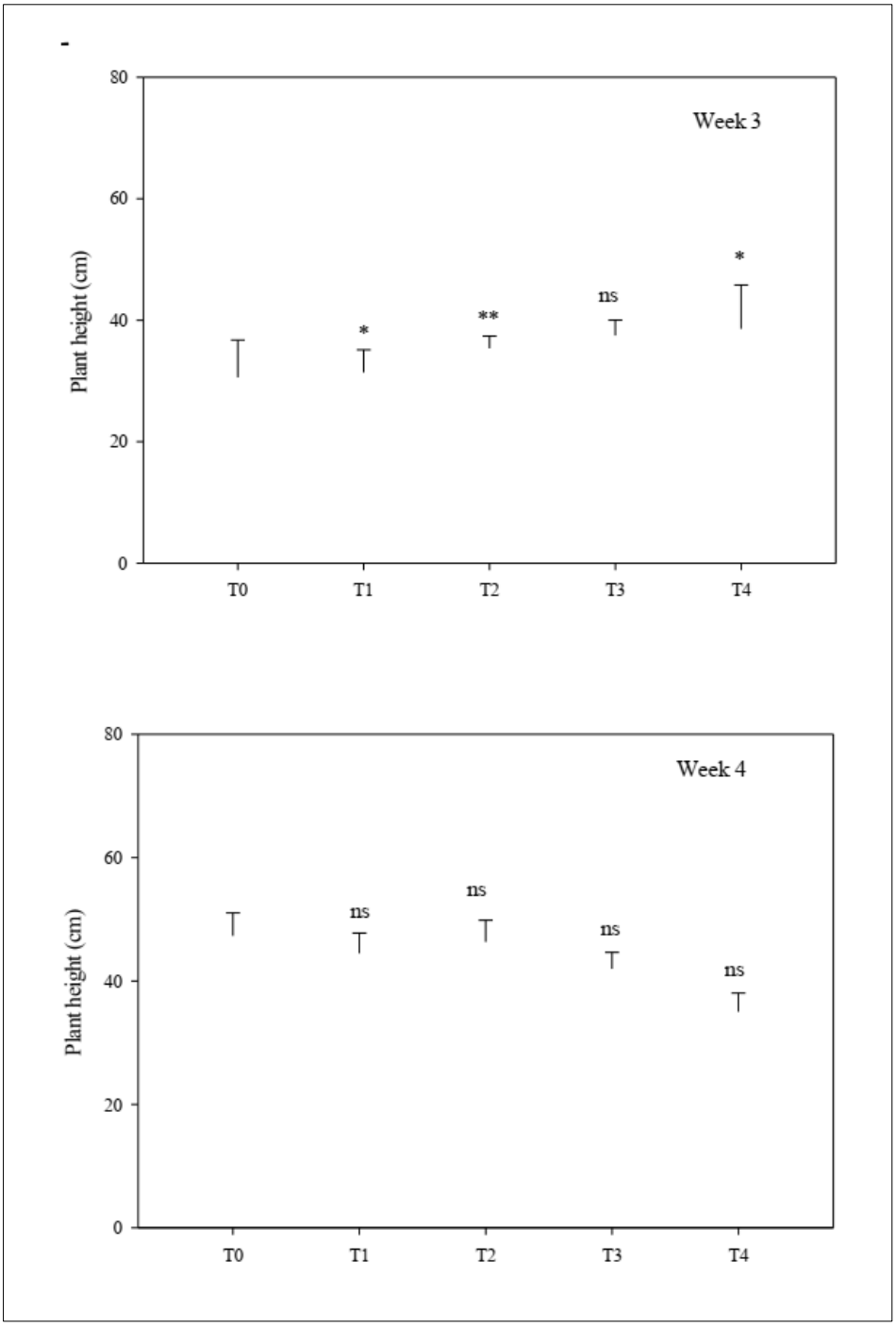


Figure 4.2: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 3rd week and during 4th week

The length of plants during 5th week after salt treatment was ranged from 38cm to 55cm in T4 to T0 respectively. The treatments T1, T2, T3, T4, were showing nonsignificant difference with T0 (control) During week 6th week the length of plant ranged from 42cm to 55cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non- significant difference with T0 (control).

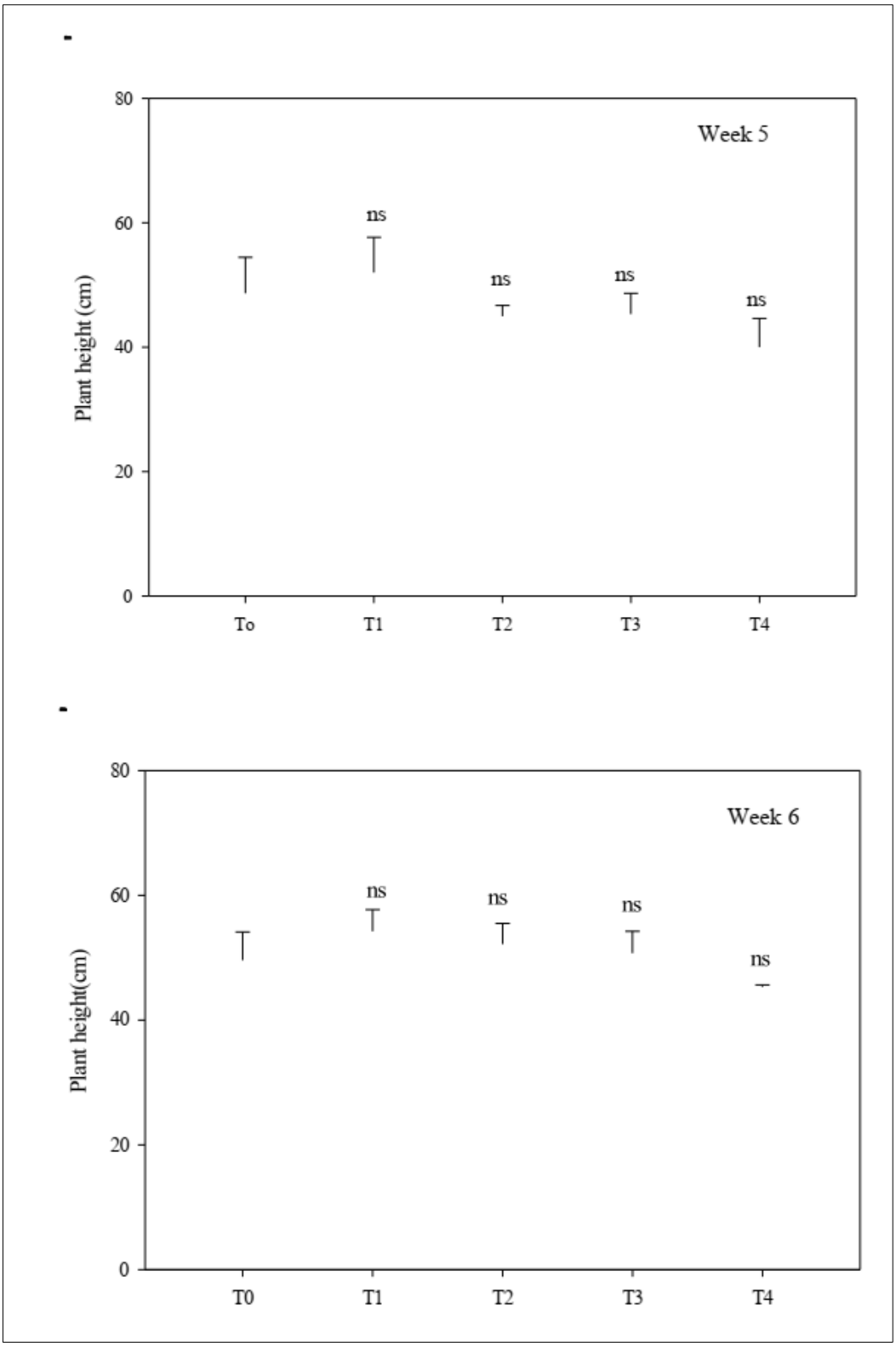


Figure 4.3: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 5th week and during 6th week.

The length of plants during 7th week after salt treatment was ranged from 45cm to 56cm in T4 to T0 respectively. The treatments T1, T2, T3, T4, were showing nonsignificant difference with T0 (control) During week 8th week the length of plant ranged from 55cm to 58cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non- significant difference with T0 (control).

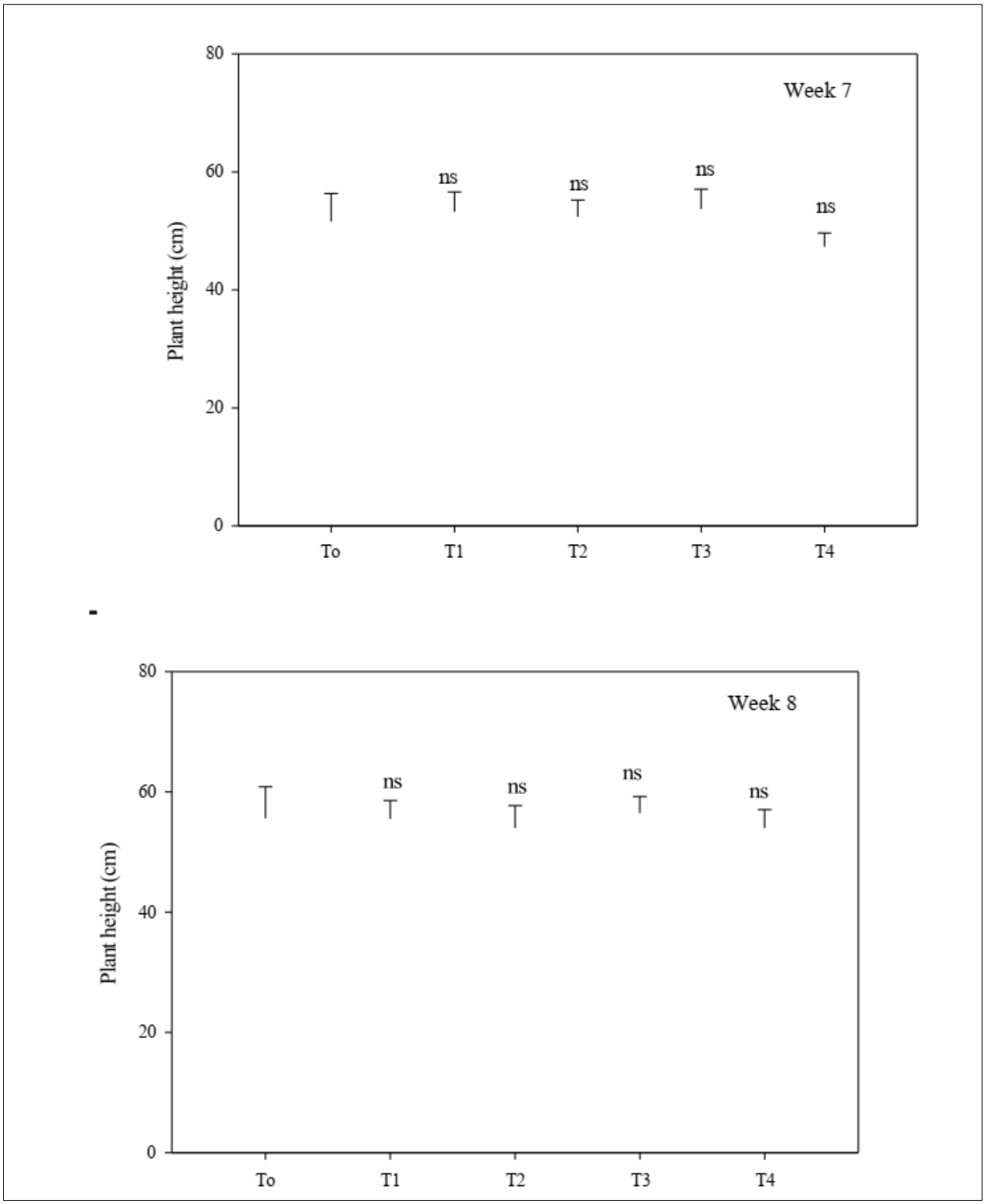


Figure 4.4: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 7th week and during 8th week.

The length of plants during 9th week after salt treatment was ranged from 58cm to 62cm in T4 to T0 respectively. The treatments T1, T2, T3, T4, were showing nonsignificant difference with T0 (control) During week 10th week the length of plant ranged from 55cm to 63cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non- significant difference with T0 (control).

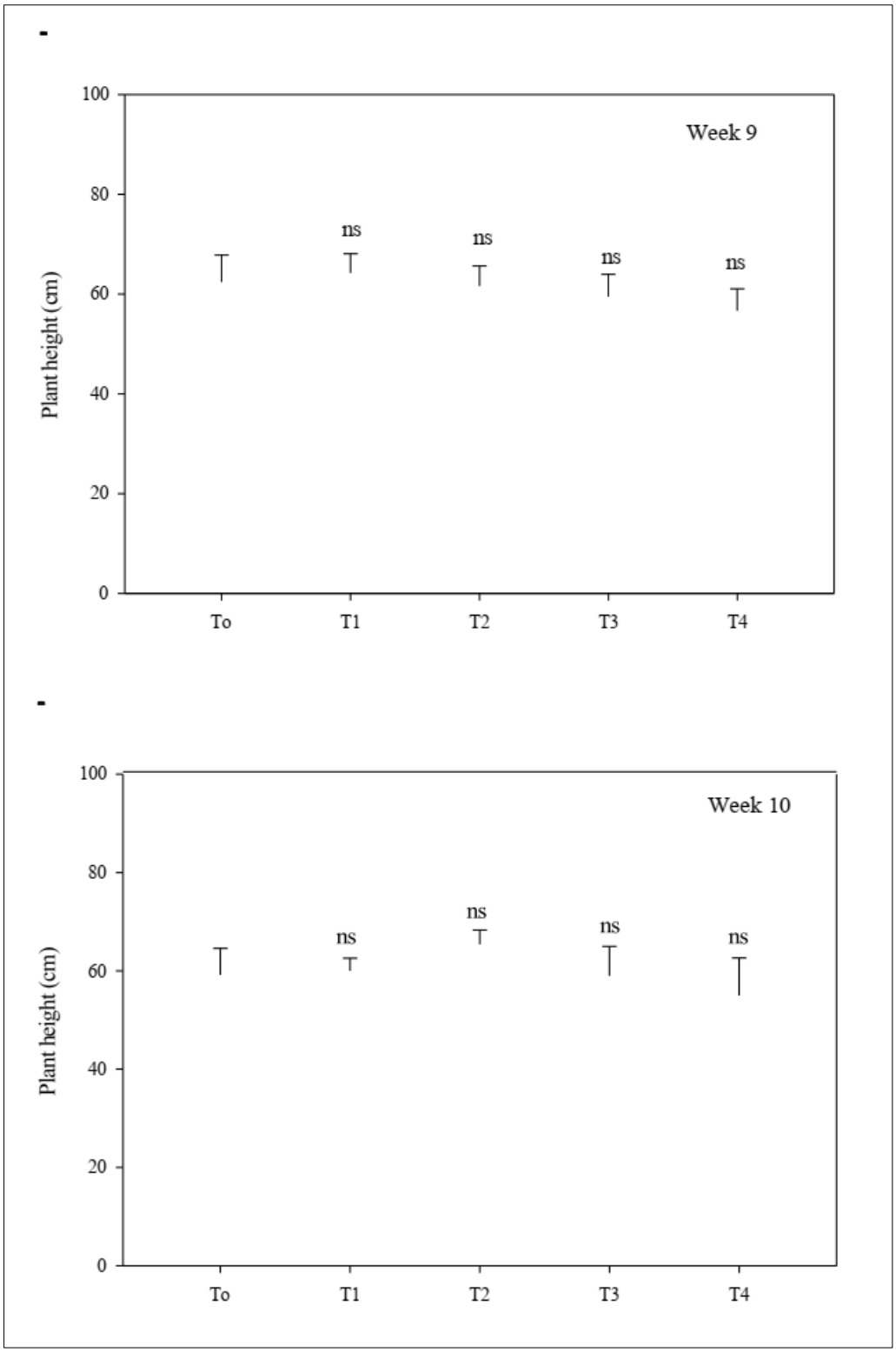


Figure 4.5: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 9th week, and during 10th week.

The length of plants during 11th week after salt treatment was ranged from 58cm to 62cm in T4 to T0 respectively. The treatments T1, T2, T3, T4, were showing nonsignificant difference with T0 (control) During week 12th week the length of plant ranged from 58cm to 62cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non- significant difference with T0 (control).

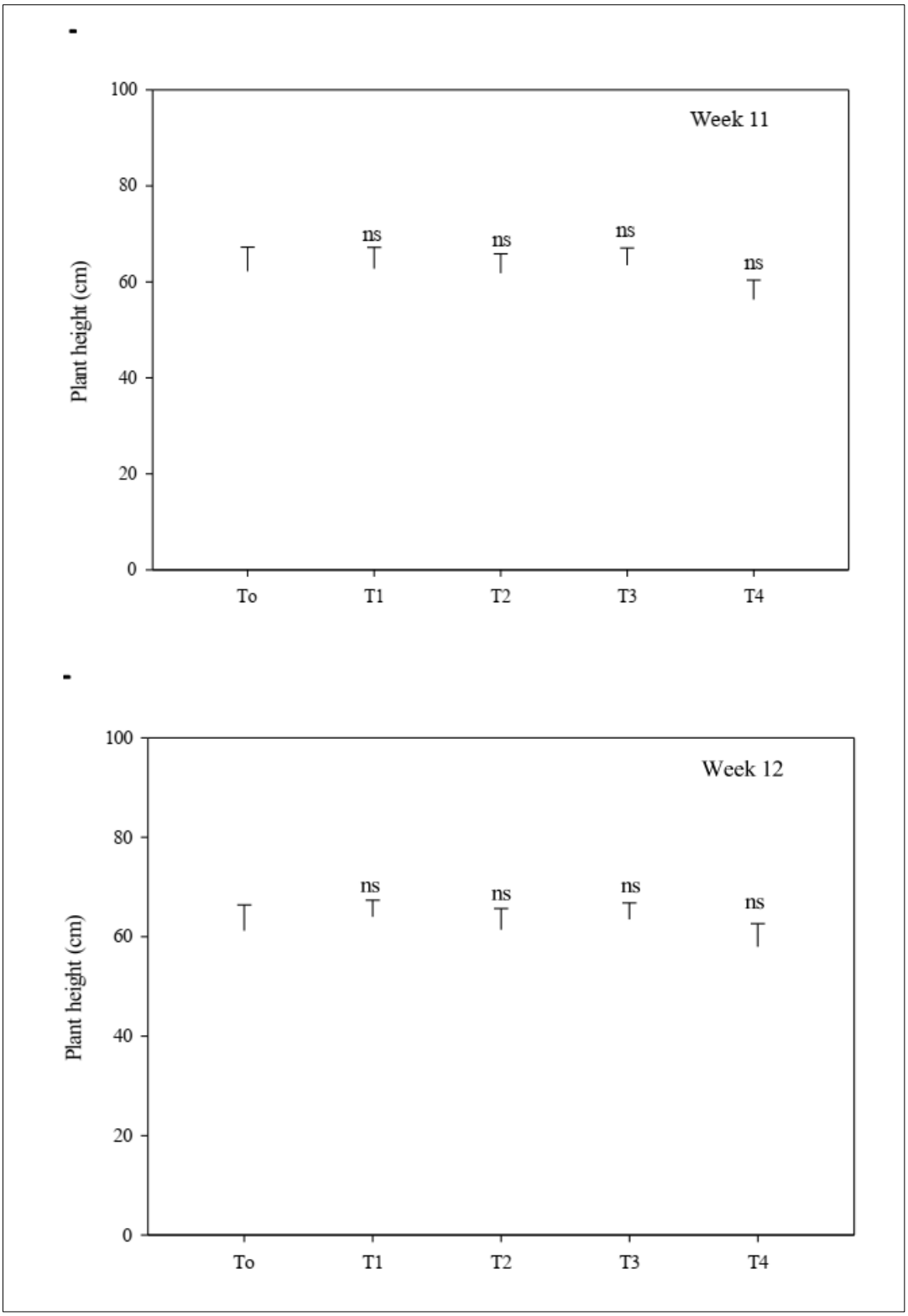


Figure 4.6: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 11th week and during 12th week

The length of plants during 13th week after salt treatment was ranged from 55cm to 60cm in T4 to T0 respectively. The treatments T1, T2, T3, T4, were showing nonsignificant difference with T0 (control) During week 14th week the length of plant ranged from 55cm to 62cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non- significant difference with T0 (control).

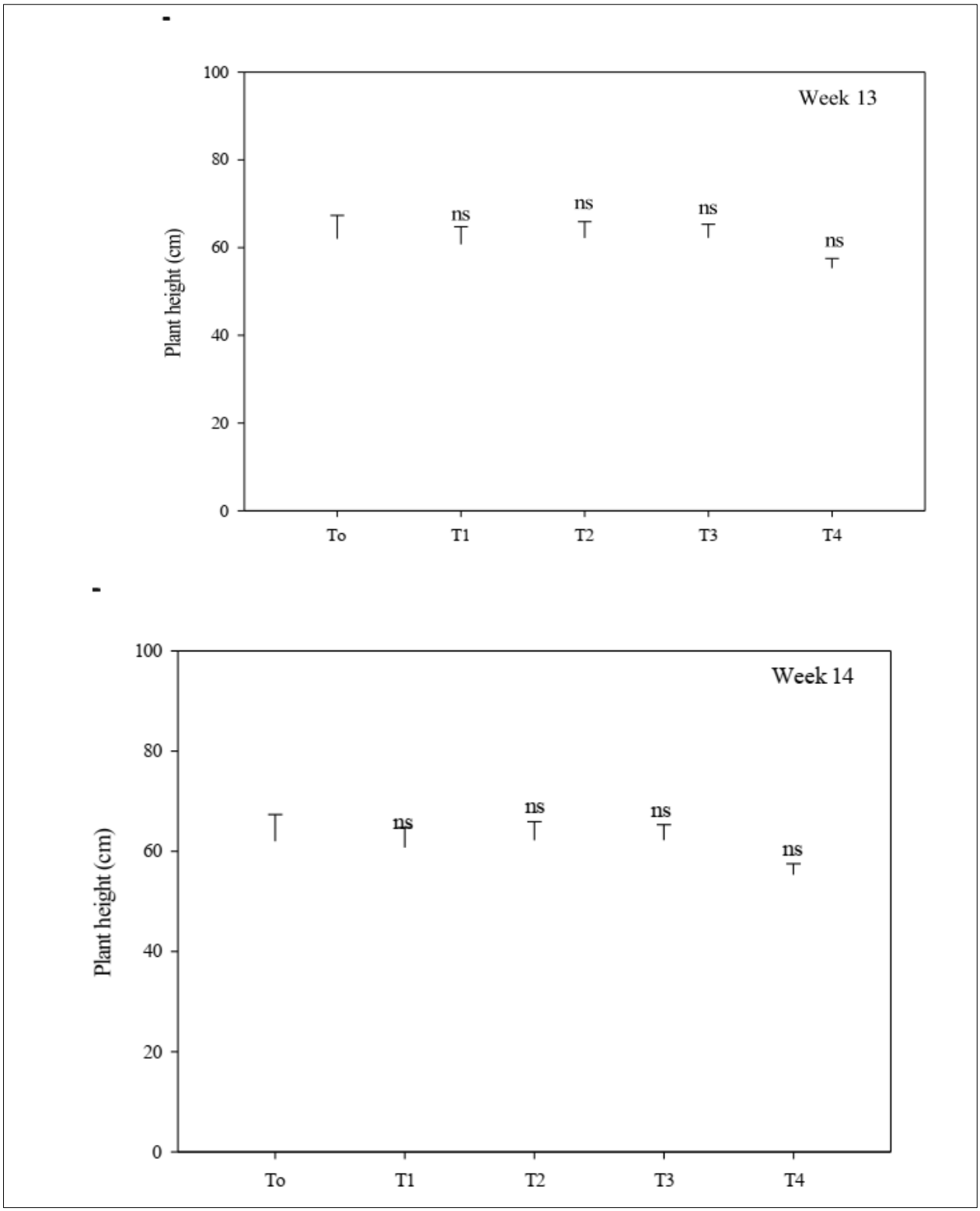


Figure 4.7: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 13th week and during 14th week

4.1.1 Number of Leaves of Oryza Sativa cv. Super Kainat Exposed to Salt Treatment (NaCl):

The number of leaves during week 1 ranged from 3 to 7 in T4 and T0 respectively. The treatment T4 showing non-significant difference but treatments T1, T2, T3, were showing the significant difference with control group T0. During week 2nd number of leaves ranged from 3 to 6 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control) (Figure 4.1).

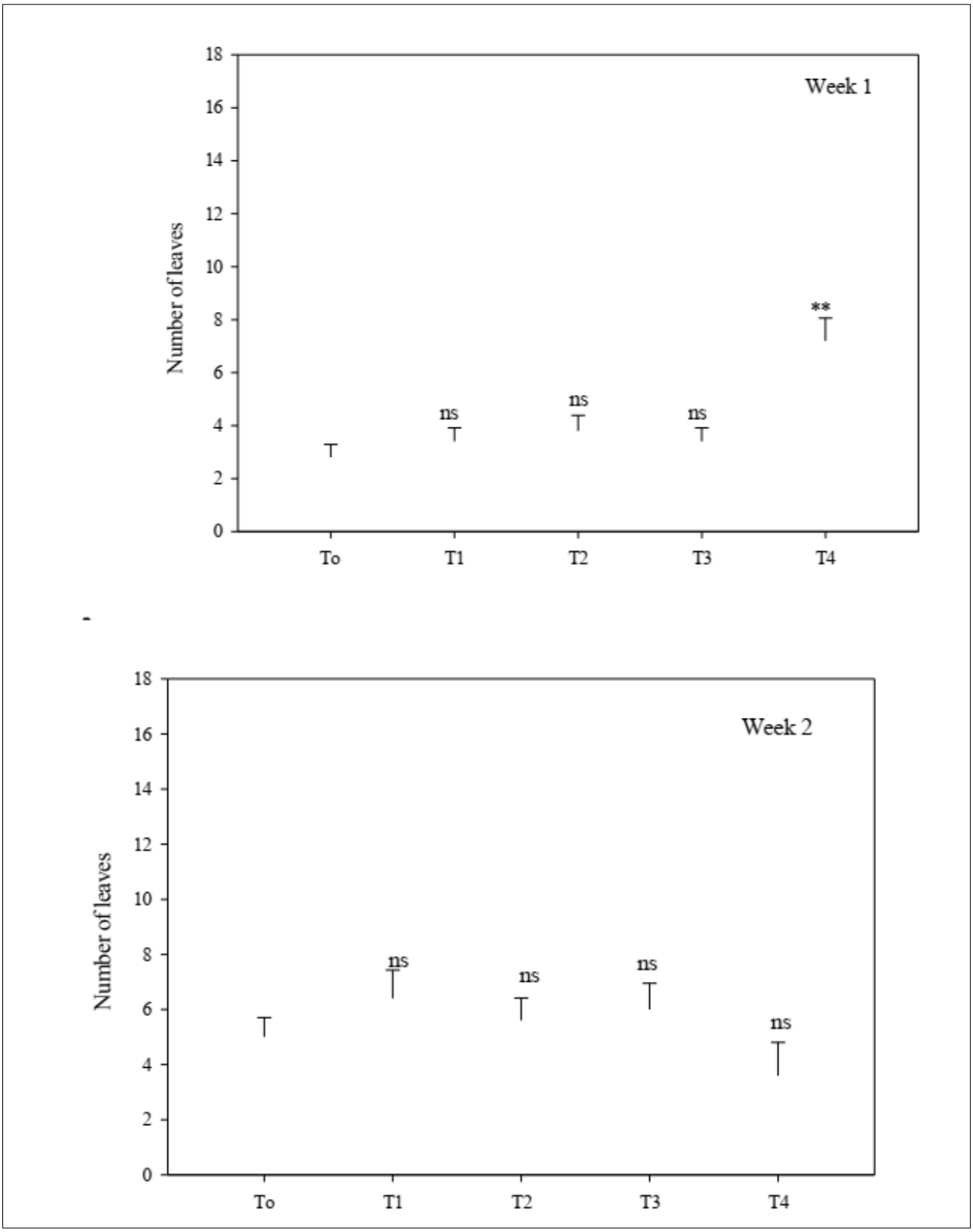


Figure 4.1.1: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 1 and during week 2

The number of leaves during week 3rd ranged from 4 to 7 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 4th number of leaves ranged from 5 to 7 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control).

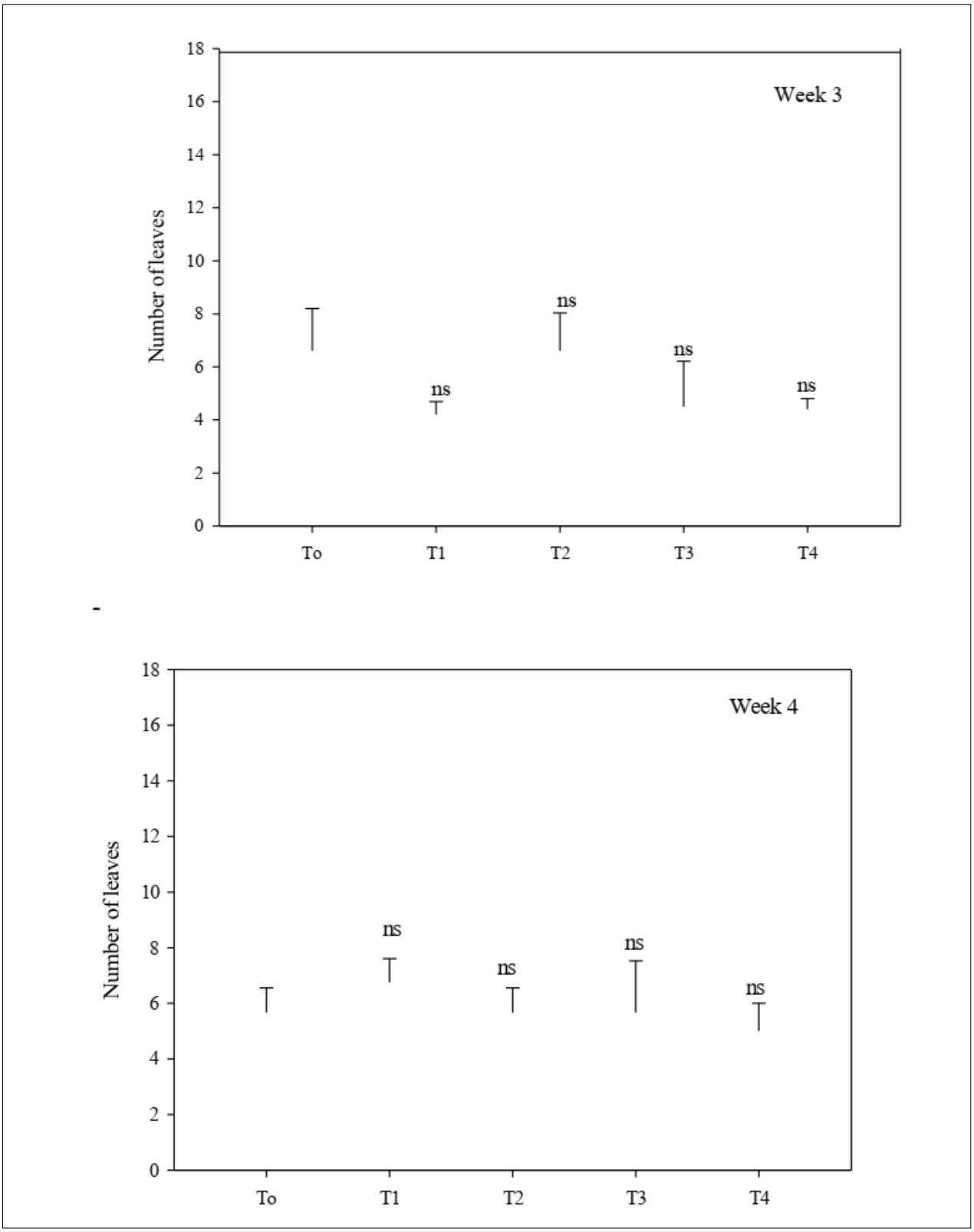


Figure 4.1.2: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 3 and during week 4.

The number of leaves during week 5th ranged from 5 to 9 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 6th number of leaves ranged from 5 to 9 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control).

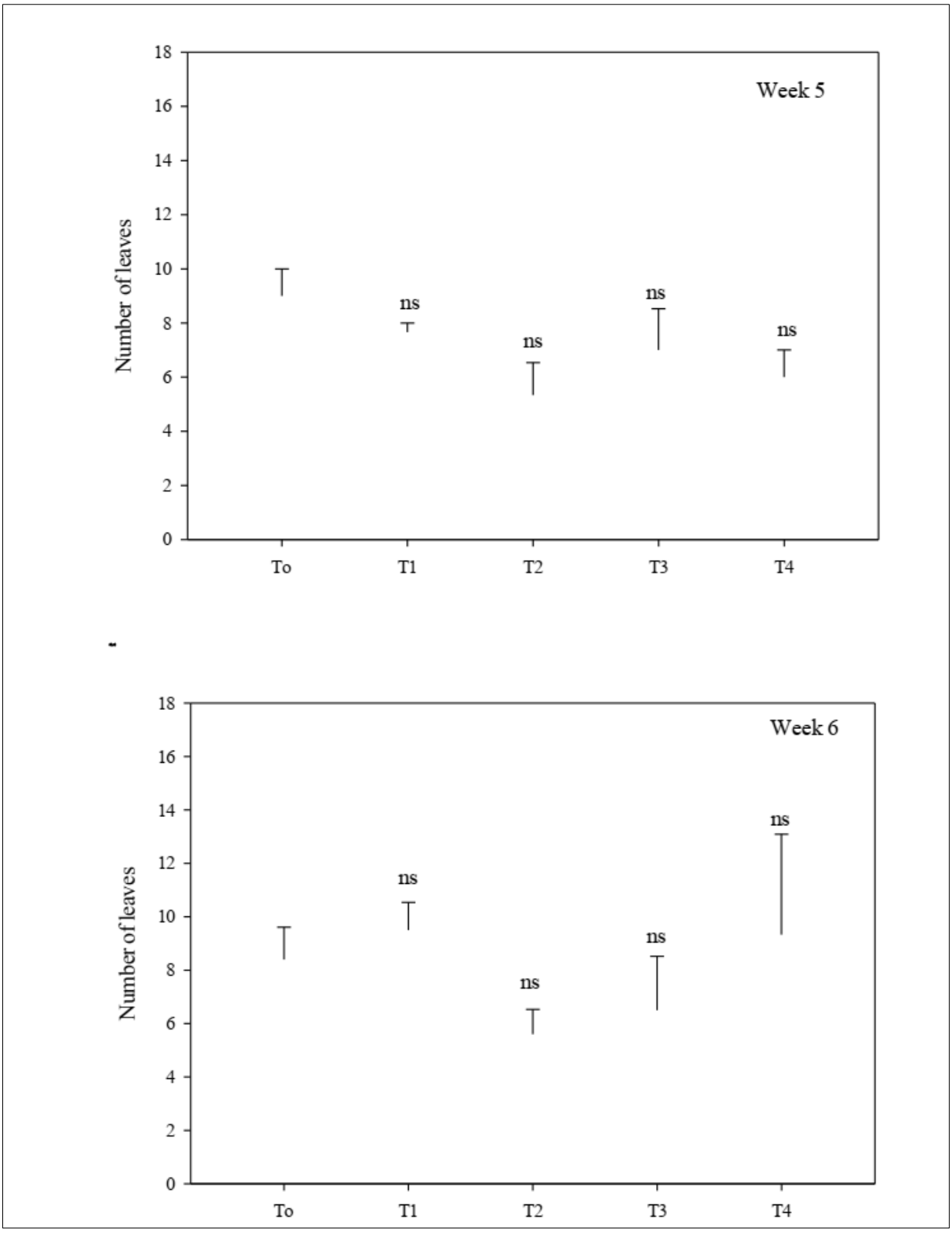


Figure 4.1.3: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 5 and during week 6.

The number of leaves during week 7th ranged from 6 to 11 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 8th number of leaves ranged from 6 to 10 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control).

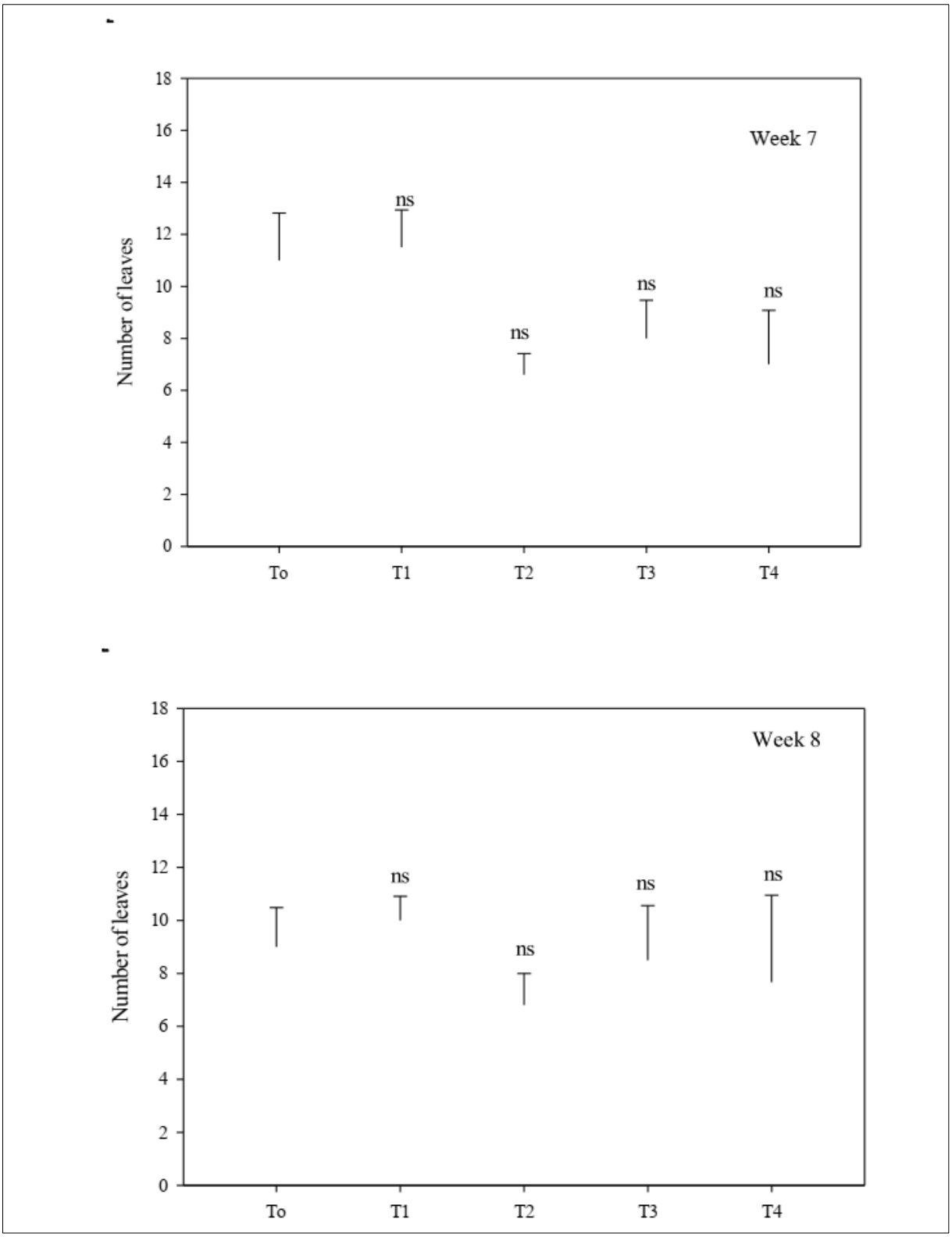


Figure 4.1.4: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 7 and during week 8.

The number of leaves during week 9th ranged from 5 to 9 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 10th number of leaves ranged from 5 to 11 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control).

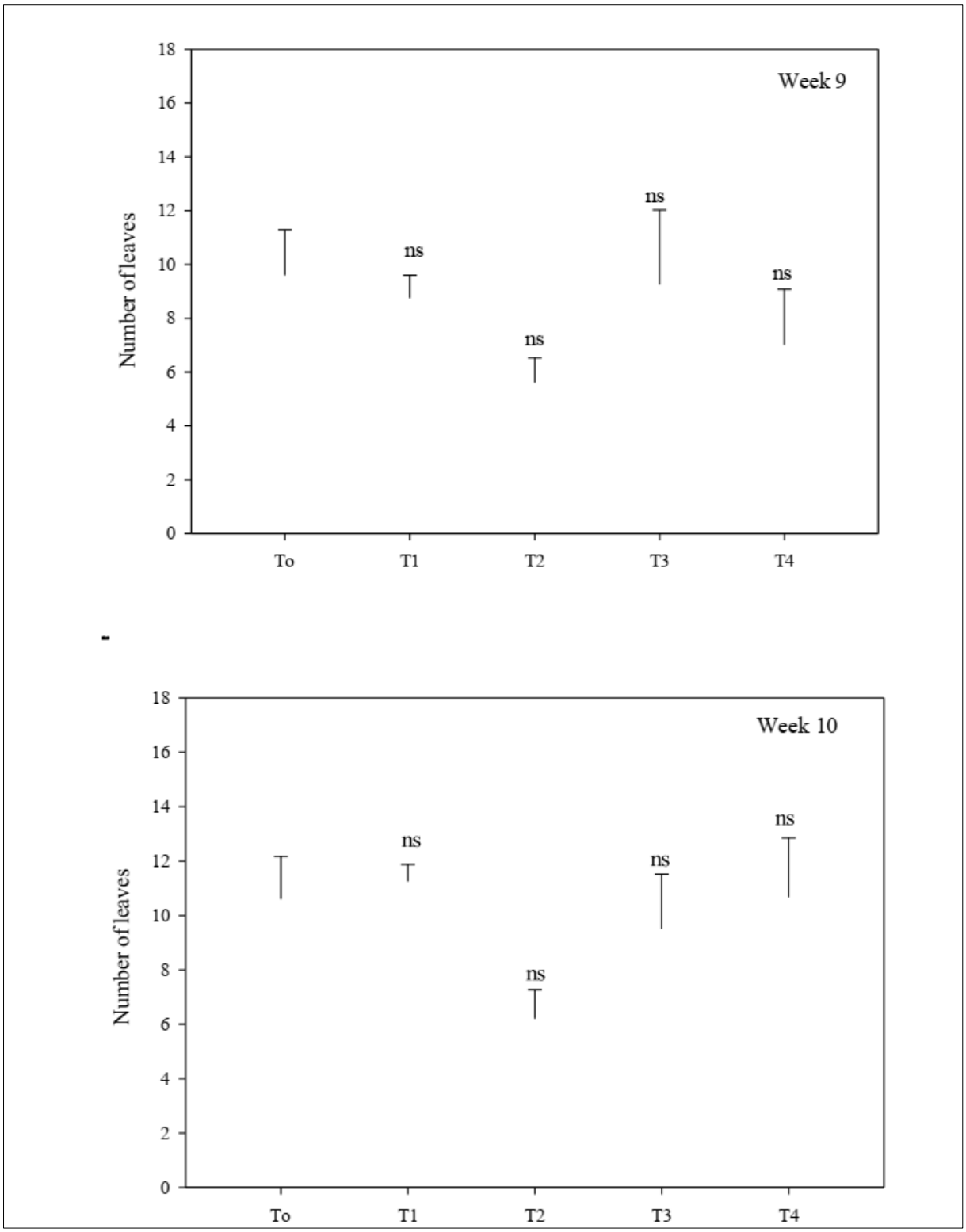


Figure 4.1.5: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 9 and during week 10.

The number of leaves during week 11th ranged from 6 to 11 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 12th number of leaves ranged from 7 to 13 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control).

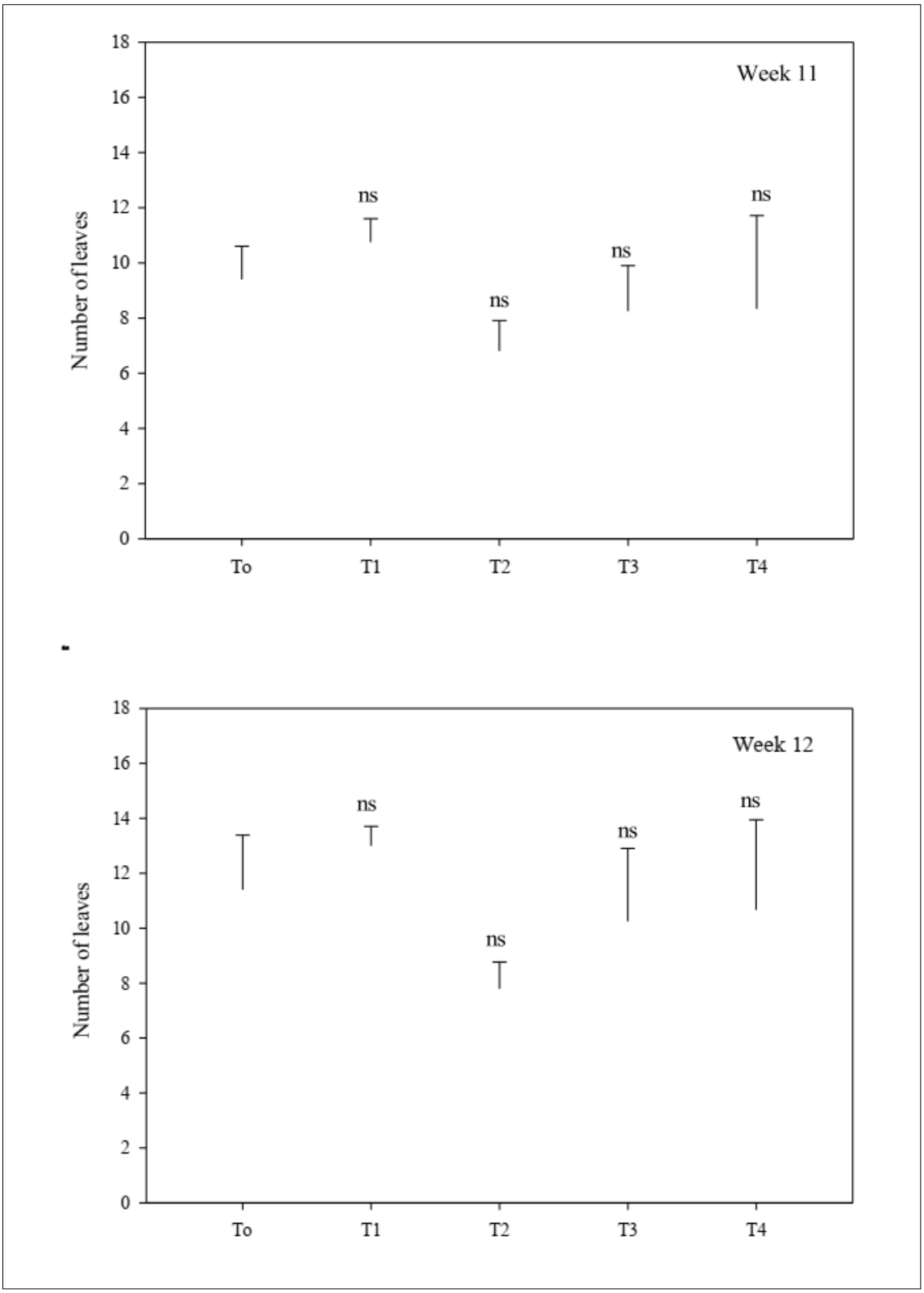


Figure 4.1.6: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 11 and during week 12.

The number of leaves during week 13th ranged from 5 to 11 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control. During week 14th number of leaves ranged from 5 to 11 in T4 and T0 respectively and T1, T2, T3 and T4 was showing non-significant difference with T0 (control). Figure.4.7.

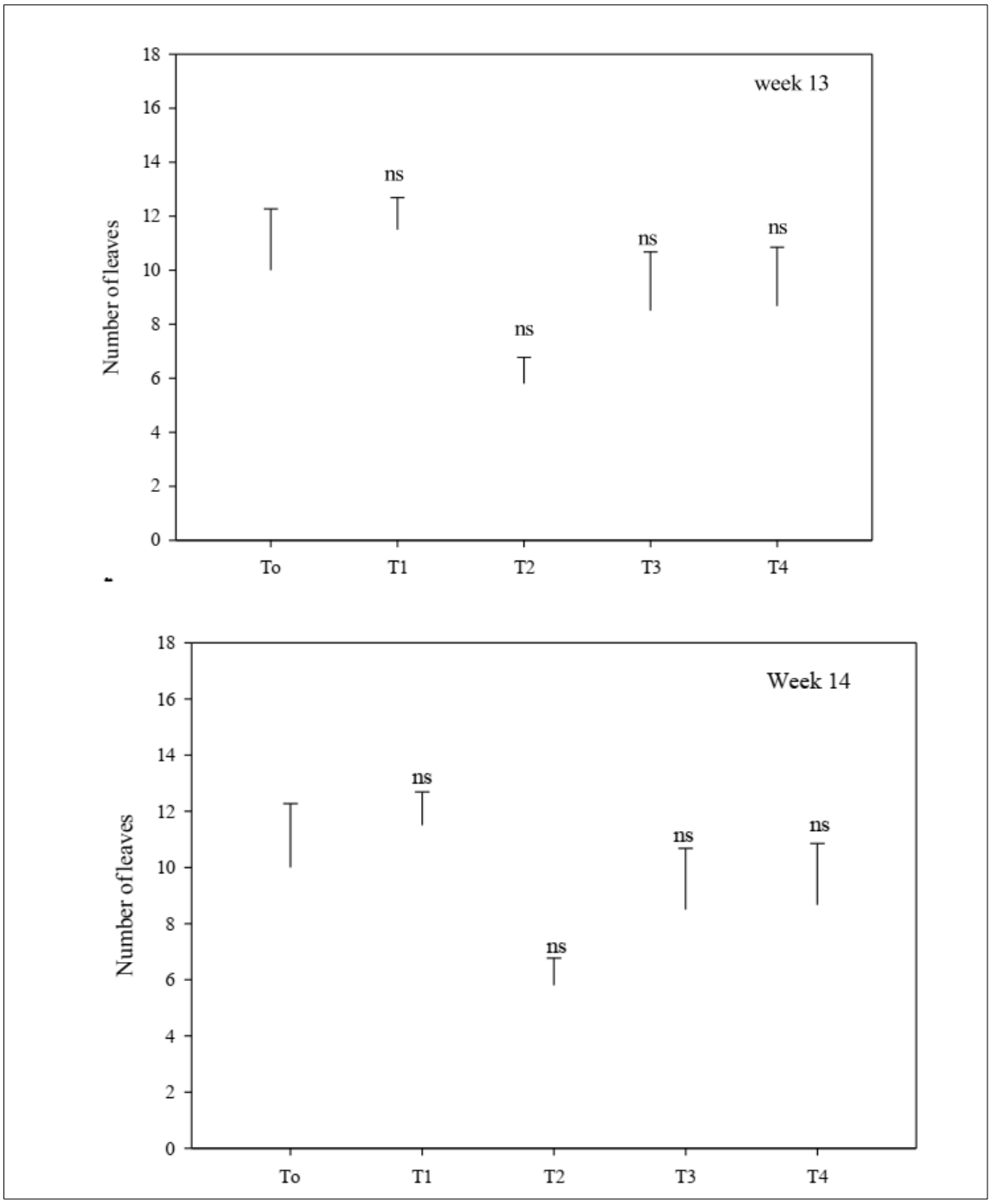


Figure 4.1.7: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 13 and during week 14.

4.1.8. Sodium (Na^+) Uptake by Roots, Shoots, Leaves and Grains of Oryza Sativa cv. Super Kainat:

Na^+ in shoots ranged from 90 to 165 mg/kg in T4 and T0 respectively. All treatments were showing significant difference with control group. Na^+ in roots ranged from 55 to 120 mg/kg in T4 and T0 respectively. All treatments were showing significant difference with T0 (control) except T1. Meanwhile Na^+ in Leaves ranged from 30 to 80 mg/kg in T4 and T0 respectively. All treatments were showing significant difference with T0 (control). Na^+ In grains ranged from 2.5 to 4.5 mg/kg in T4 to T0 respectively. All treatments were showing significant difference with T0 (control). In shoots the uptake of sodium level was maximum in T3 as compare to others treatments and minimum in T4. In roots uptake level of sodium was maximum in T4 as compare to others treatments and T4 and T0 showing minimum level. In leaves among all the treatments T2 and T3 had maximum sodium uptake and minimum in T0. In grains maximum sodium uptake in T1while minimum in T3 treatment.

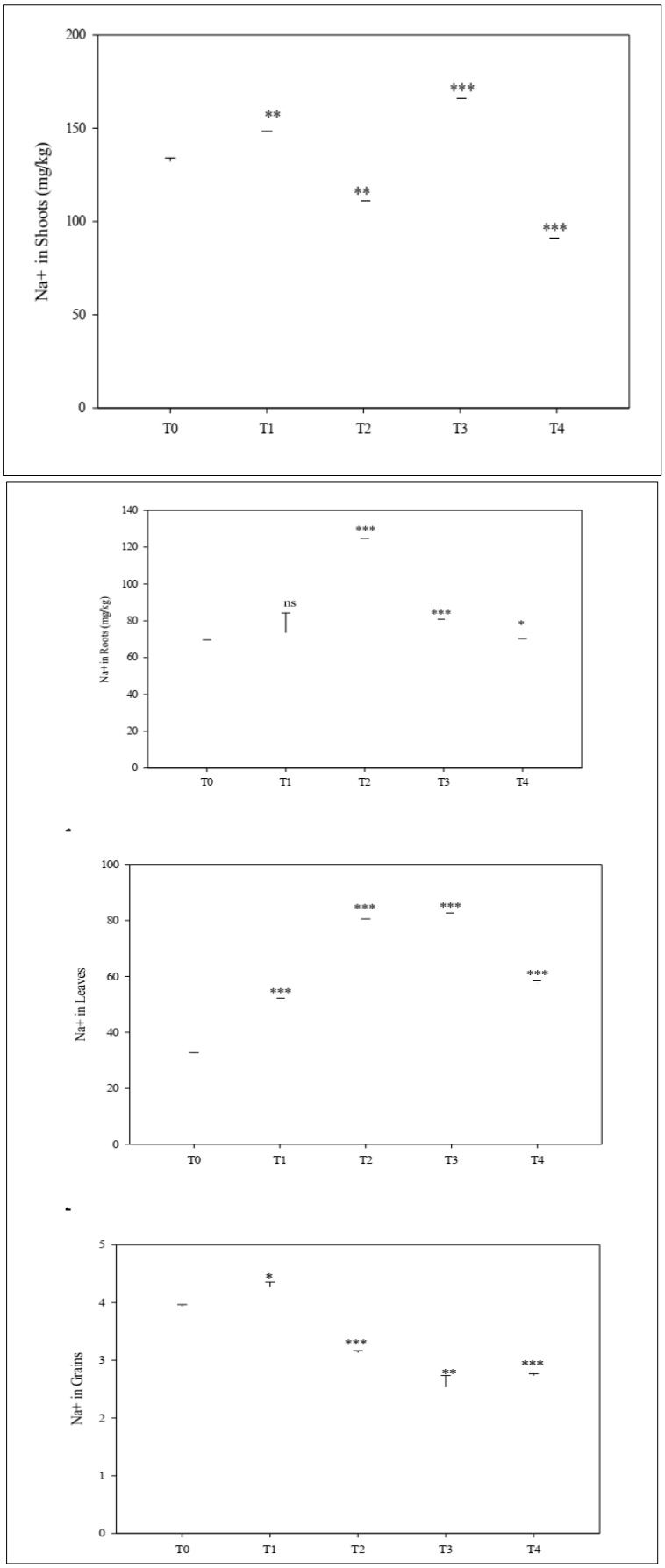


Fig. 4.1.8: Showing uptake of N^+ by roots, shoots, leaves and grains in rice plant

4.2. Length of Oryza Sativa Cultivar Super Kainat after Salt Treatment (LiCl):

The length of plants during 1st week after salt treatment was ranged from 35cm to 38cm in T4 to T0 respectively. All treatments were showing nonsignificant difference with T0 (control). During week 2nd the length of plant ranged from 36cm to 38cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control).

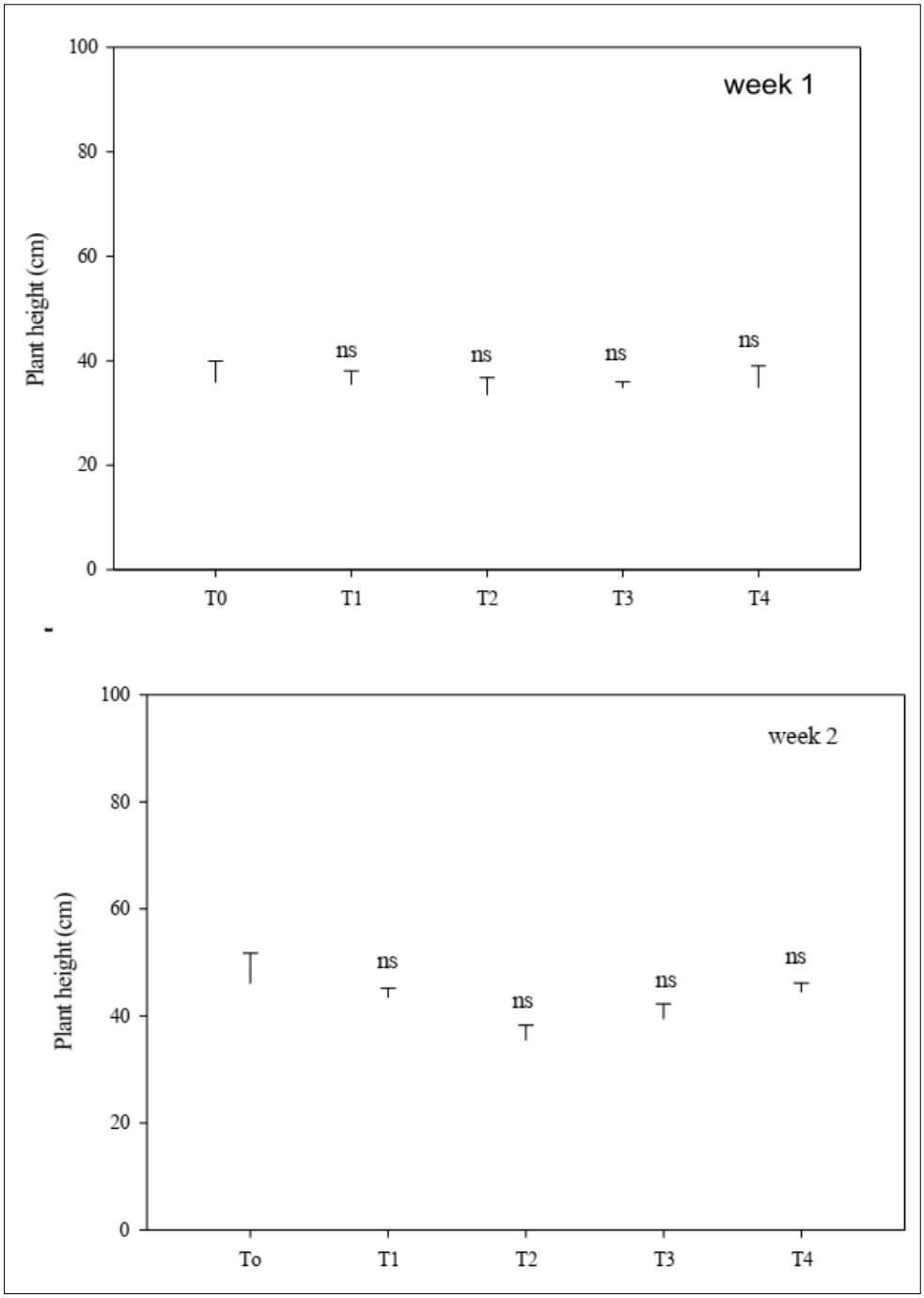


Figure 4.2.1: Showing the mean ± SE in *Oryza sativa* cv. Super Kainat, ns indicate non- significant difference during 1st week and during 2nd week.

The length of plants during 3rd week after salt treatment was ranged from 35cm to 42cm in T4 to T0 respectively. All treatments were showing nonsignificant difference with T0 (control). During week 4th the length of plant ranged from 40cm to 60cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control).

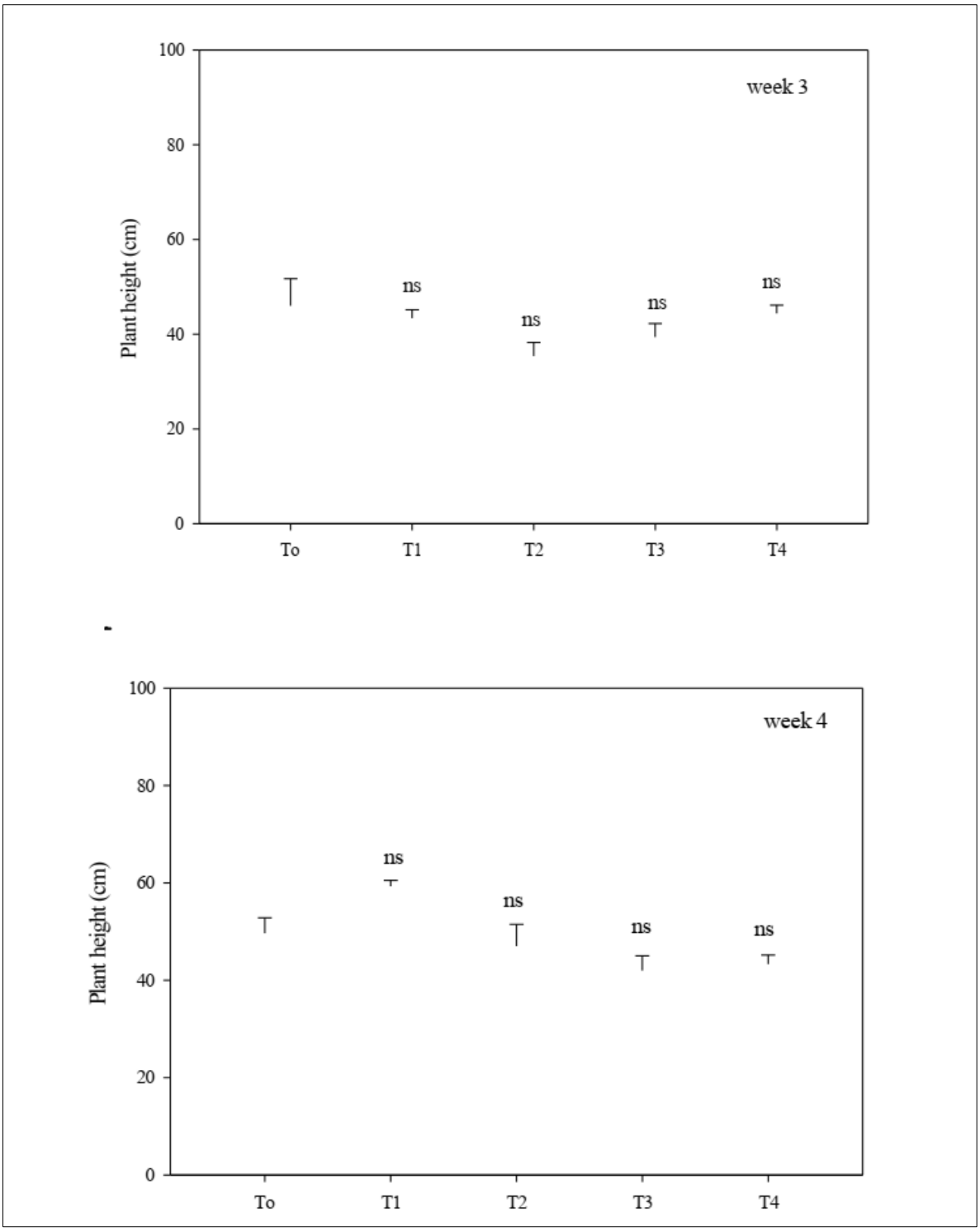


Figure 4.2.2: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 3rd week and during 4th week

The length of plants during 5th week after salt treatment was ranged from 35cm to 60cm in T4 to T0 respectively. All treatments were showing nonsignificant difference with T0 (control). During week 6th the length of plant ranged from 50cm to 60cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control).

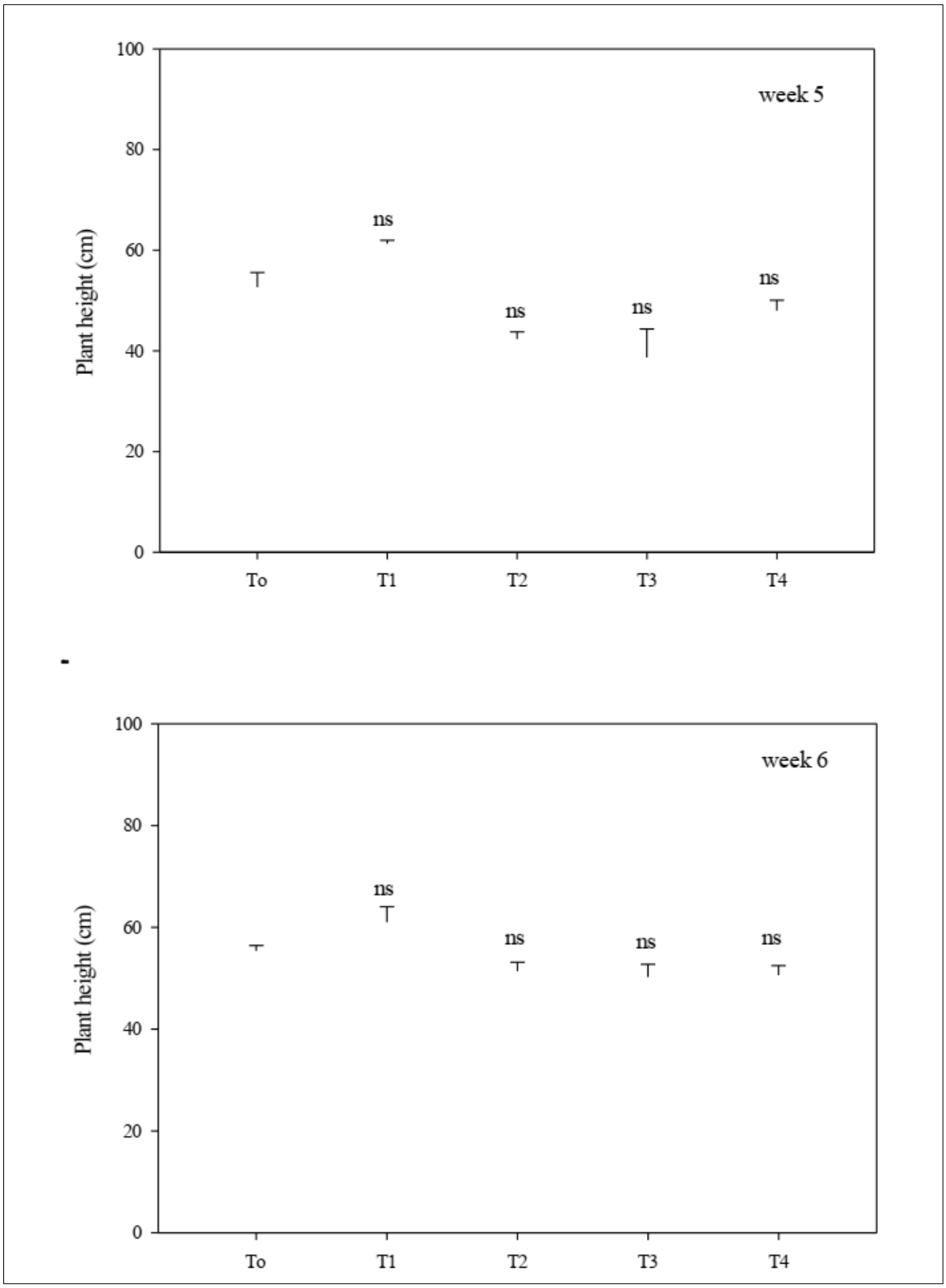


Figure 4.2.3: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 5th week and during 6th week.

The length of plants during 7th week after salt treatment was ranged from 55cm to 60cm in T4 to T0 respectively. All treatments were showing nonsignificant difference with T0 (control). During week 8th the length of plant ranged from 58cm to 62cm in T4 to T0 respectively. Treatments T1, T2, T3 and T4 were showing non-significant difference with T0 (control).

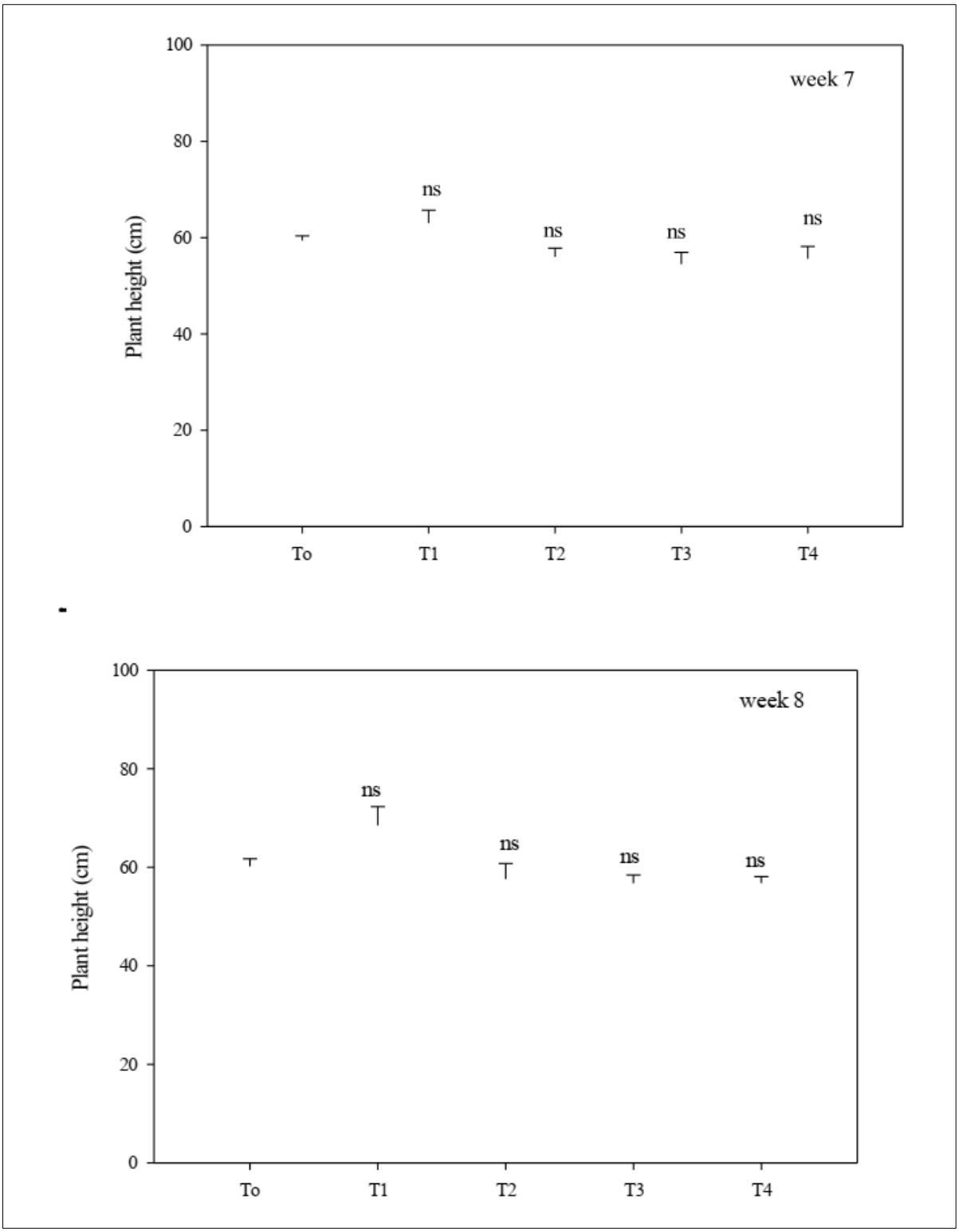


Figure 4.2.4: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 7th week and during 8th week.

The length of plants during 9th week after salt treatment was ranged from 55cm to 65cm in T4 to T0 respectively. The treatments T1 ana T2 were showing nonsignificant difference with T0 (control). While treatments T3 and T4 were showing significant difference with T0 (control). During week 10th the length of plant ranged from 55cm to 65cm in T4 to T0 respectively. Treatments T1 and T2 were showing non-significant difference with T0 (control) while treatments T3 and T4 were showing significant difference with T0 (control).

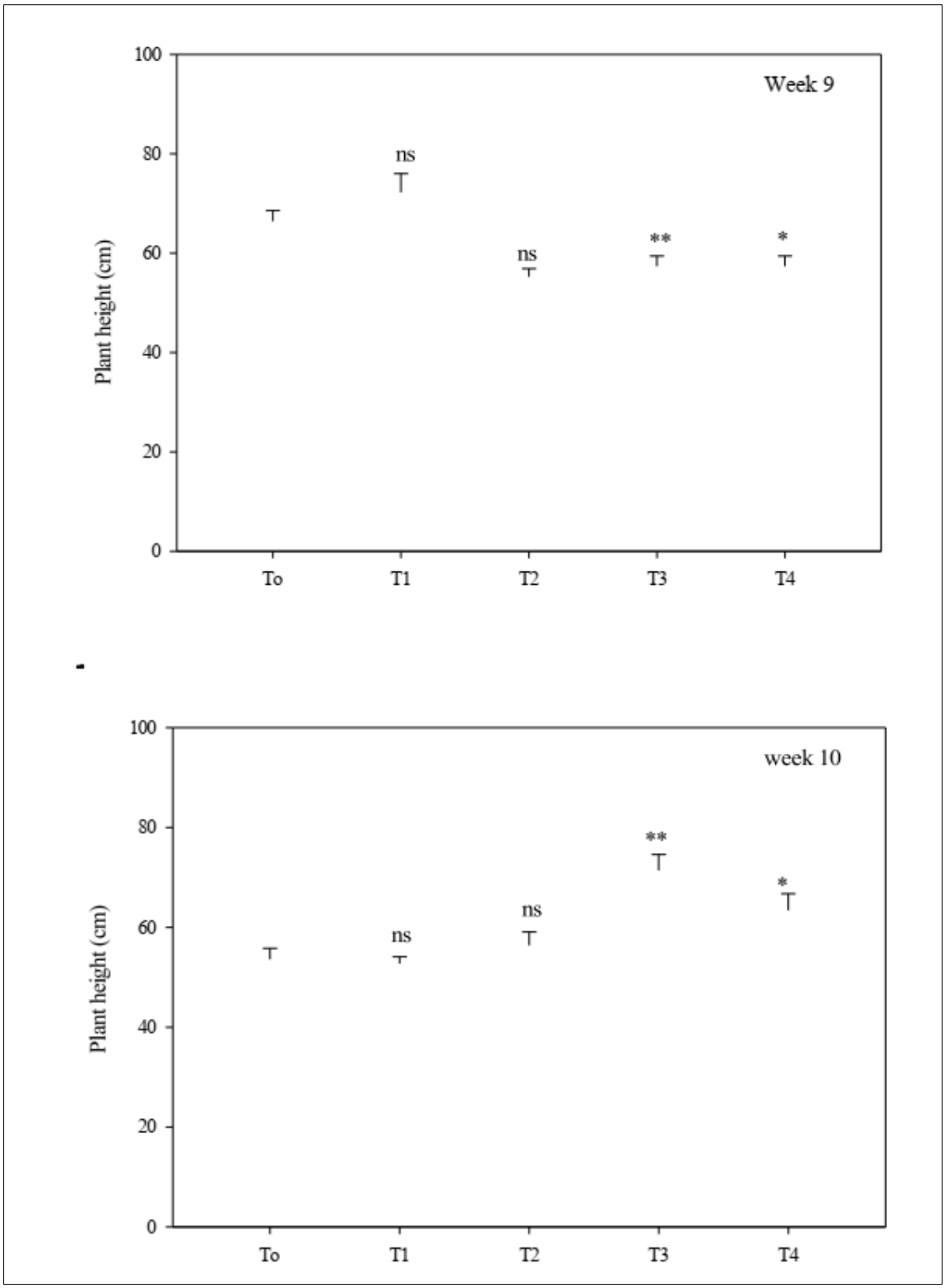


Figure 4.2.5: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 9th week and during 10th week.

The length of plants during 11th week after salt treatment was ranged from 58cm to 70cm in T4 to T0 respectively. The treatments T1was showing nonsignificant difference with T0 (control). While treatments T2, T3 and T4 were showing significant difference with T0 (control). During week 12th the length of plant ranged from 58cm to 70cm in T4 to T0 respectively. Treatments T1was showing non-significant difference with T0 (control) while treatmentsT2, T3 and T4 were showing significant difference with T0 (control).

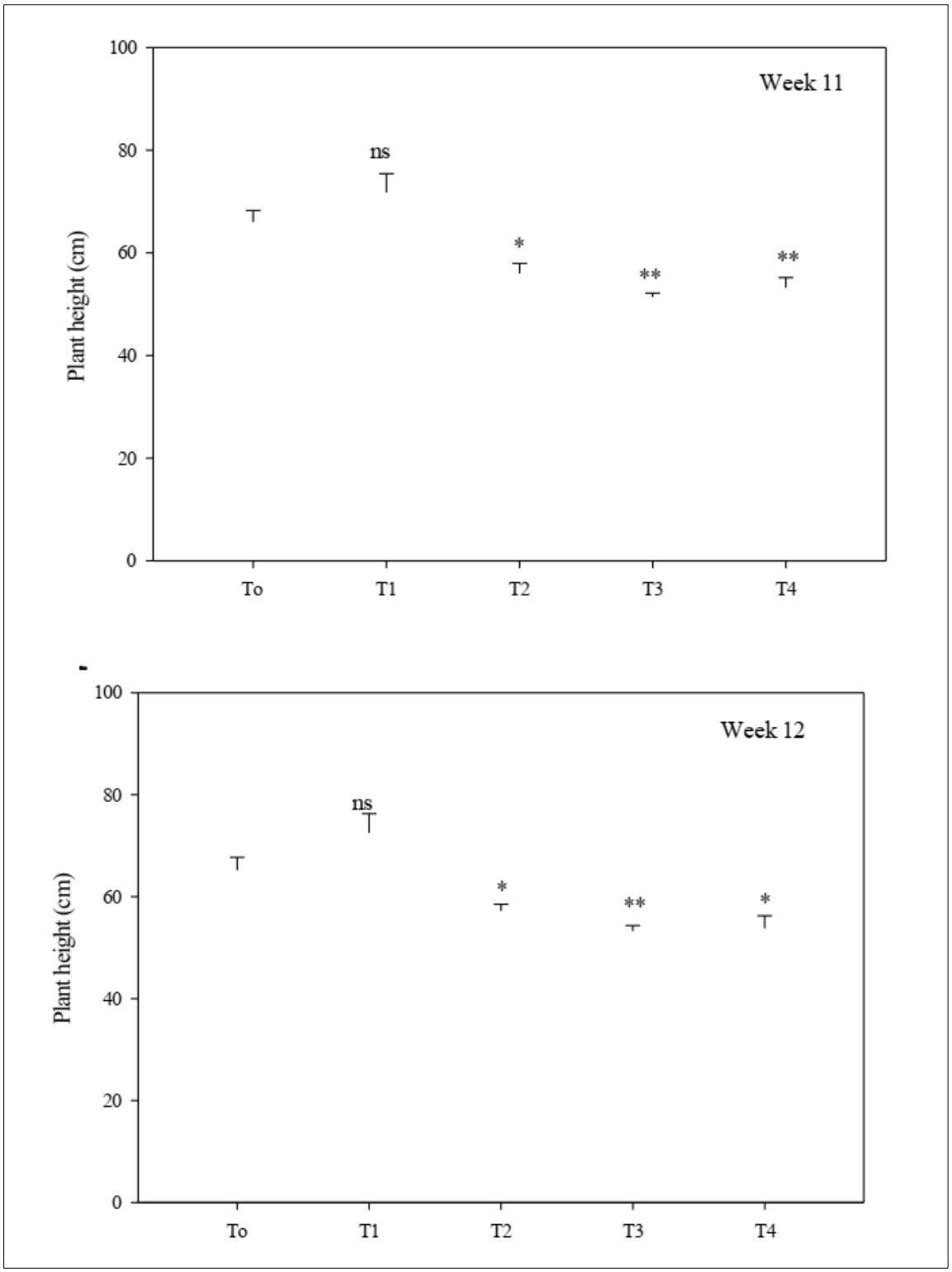


Figure 4.2.6: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 11th week and during 12th.

The length of plants during 13th week after salt treatment was ranged from 58cm to 70cm in T4 to T0 respectively. The treatments T1and T2 were showing nonsignificant difference with T0 (control). While treatments T3 and T4 were showing significant difference with T0 (control). During week 14th the length of plant ranged from 58cm to 70cm in T4 to T0 respectively. Treatments T1and T2 were showing non-significant difference with T0 (control) while treatments T3 and T4 were showing significant difference with T0 (control).

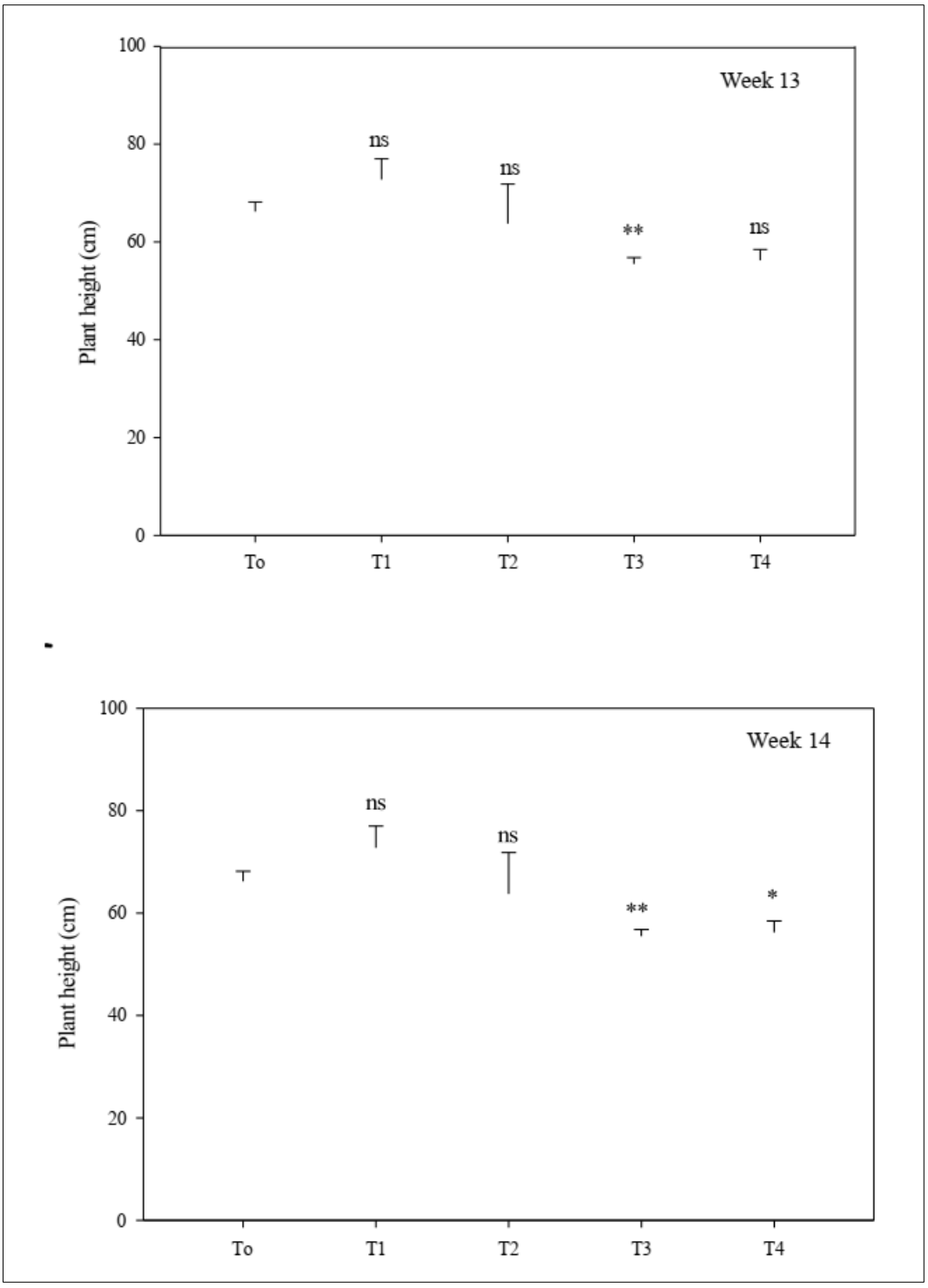


Figure 4.2.7: Showing the mean ± SE in *Oryza sativa* Super Kainat, ns indicate non- significant difference during 13th week and during 14th

4.2.2. Number of Leaves of Oryza Sativa cv. Super Kainat Exposed to (LiCl) Treatment:

The number of leaves during week 1 ranged from 6 to 10 in T4 and T0 respectively. The treatment T1,T2, T3 and T4 showing non-significant difference with control group T0. During week 2nd number of leaves ranged from 4 to 7 in T4 and T0 respectively and T1,T2,T3 and T4 was showing non-significant difference with T0 (control).

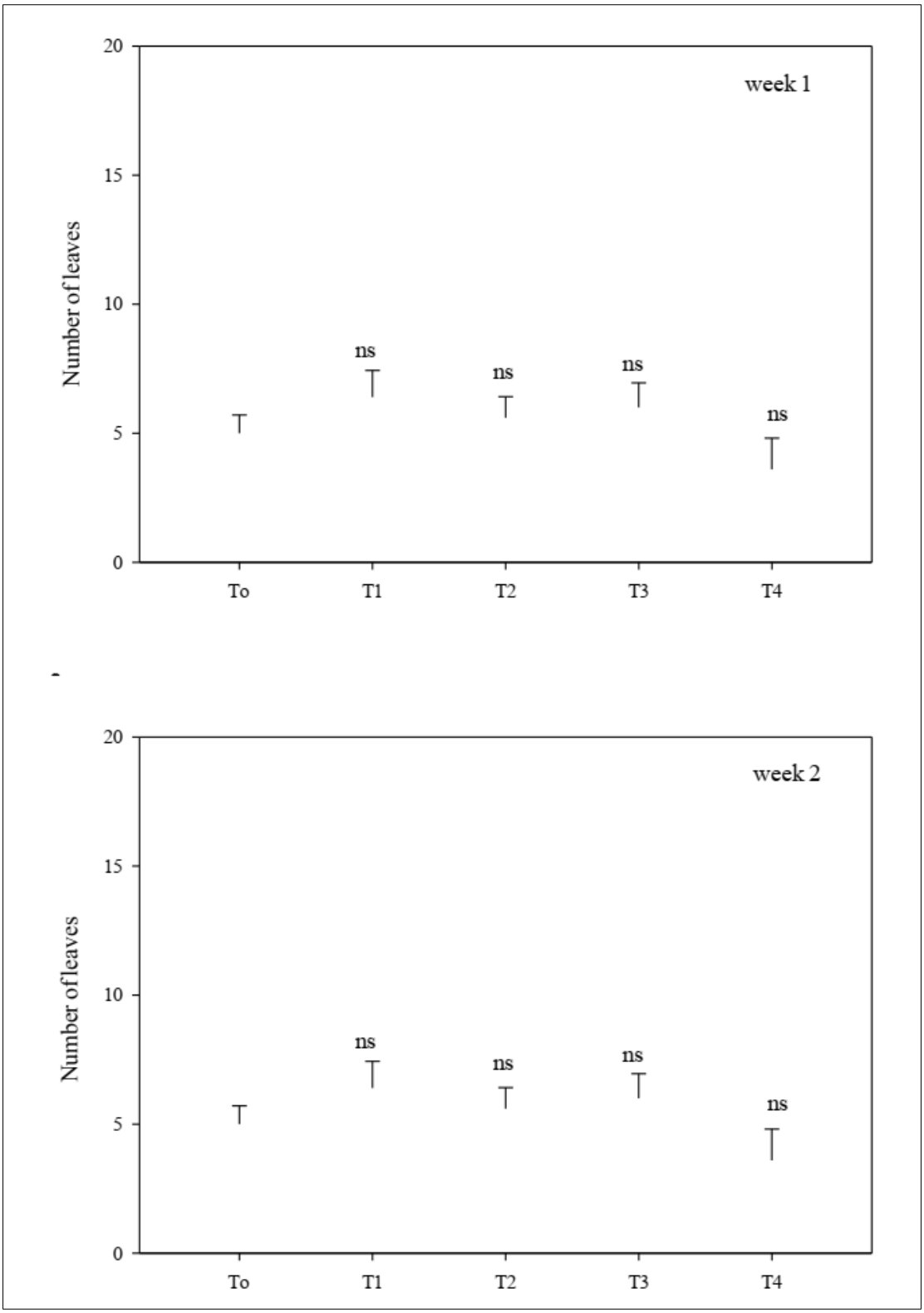


Figure 4.2.2.1: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 1 and during week 2

The number of leaves during week 3rd ranged from 4 to 7 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 4th number of leaves ranged from 4 to 8 in T4 and T0 respectively and T1, T2, and T4 was showing non-significant difference with T0 (control). While treatment T3 was showing significant difference with T0 (control).

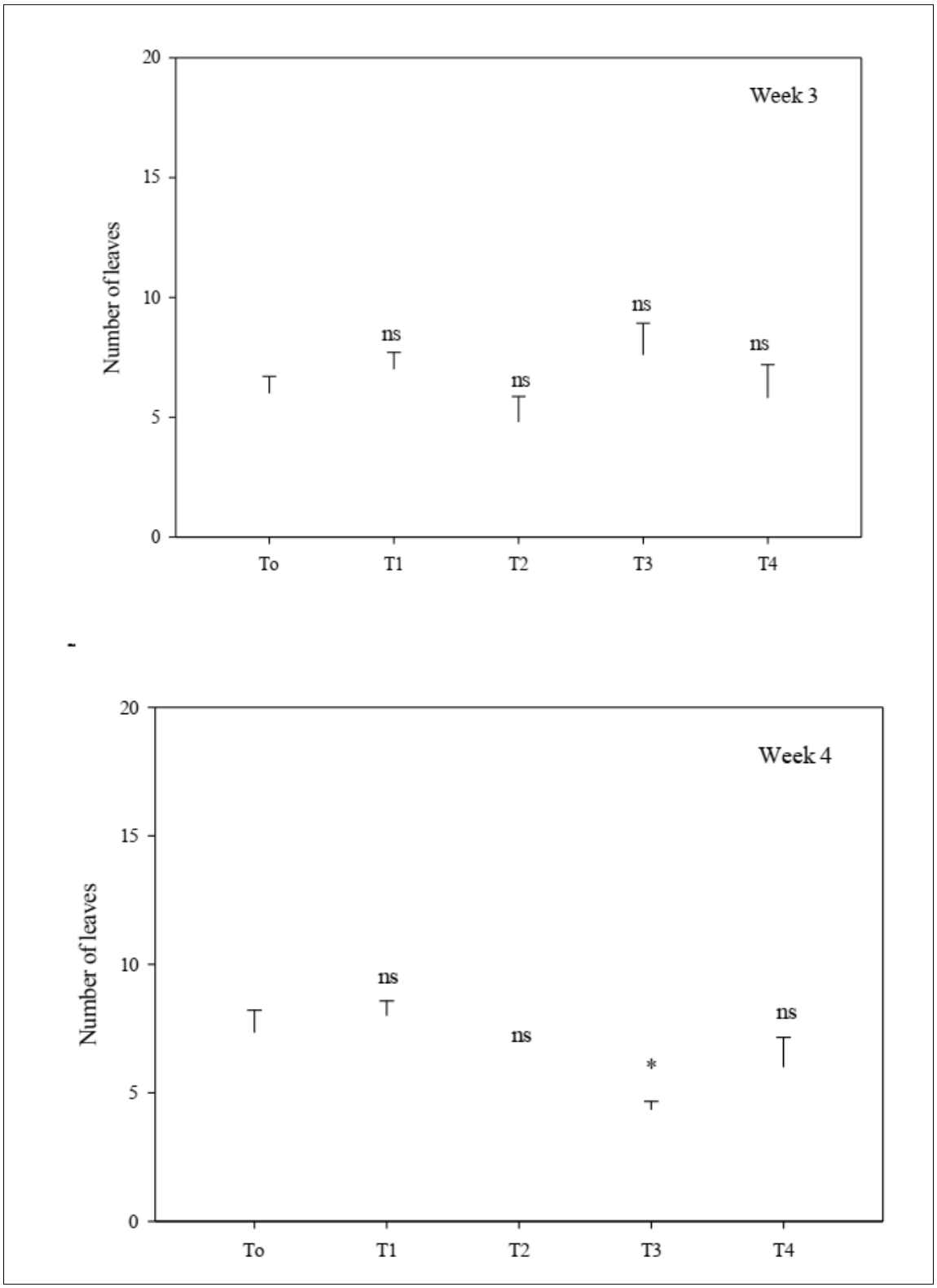


Figure 4.2.2.2: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 3 and during week 4.

The number of leaves during week 5th ranged from 3 to 12 in T4 and T0 respectively. The treatment T1,T2, T3 and T4 showing non-significant difference with control group T0. During week 6th number of leaves ranged from 5 to 10 in T4 and T0 respectively and T1, T2, and T4 was showing non-significant difference with T0 (control). While treatment T3 was showing significant difference with T0 (control).

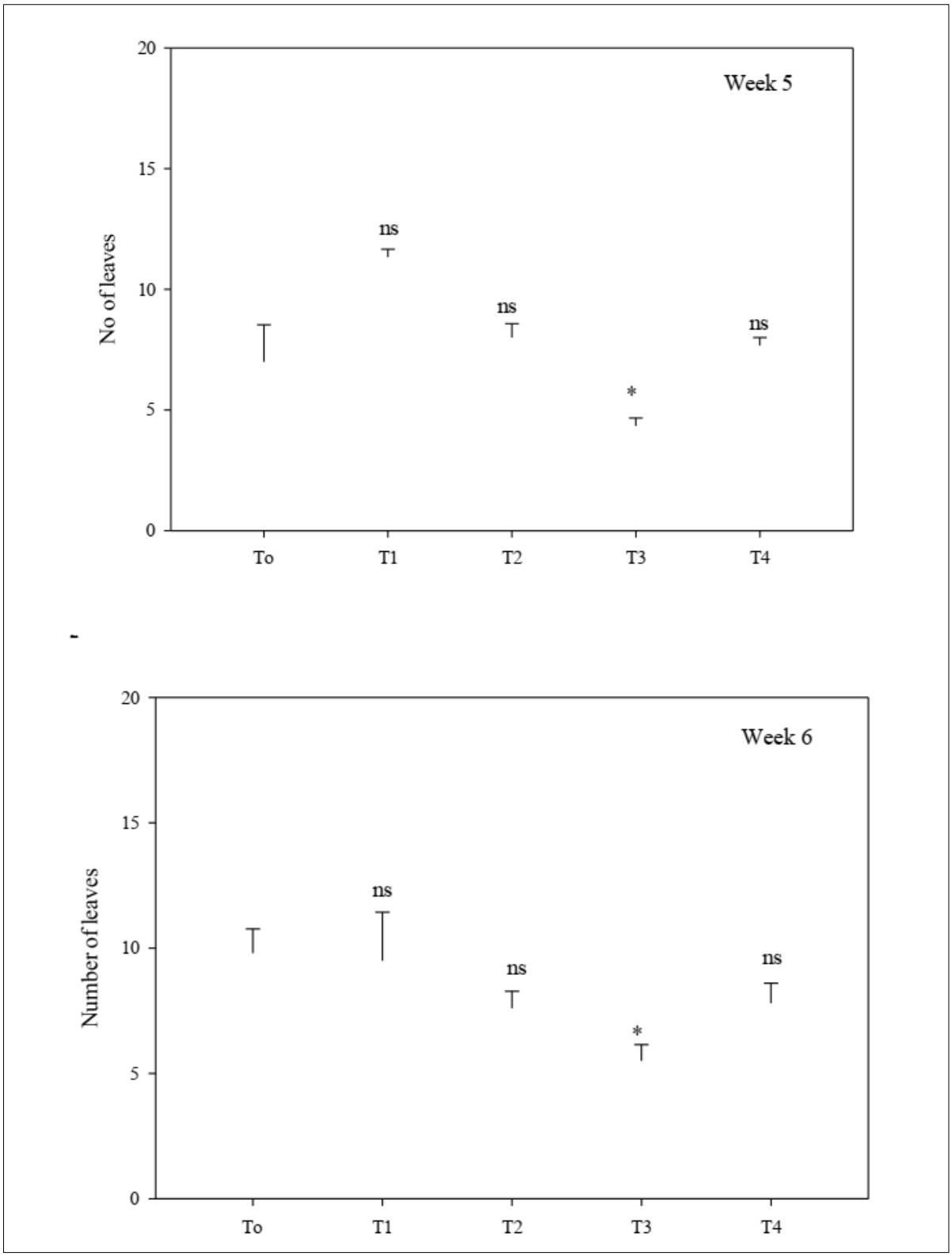


Figure 4.2.2.3: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 5 and during week 6.

The number of leaves during week 7th ranged from 7 to 12 in T4 and T0 respectively. The treatment T1,T2, and T4 showing non-significant difference while treatment T3 was showing significant difference with control group T0. During week 8th number of leaves ranged from 5 to 10 in T4 and T0 respectively and all the treatments were showing non-significant difference with T0 (control).

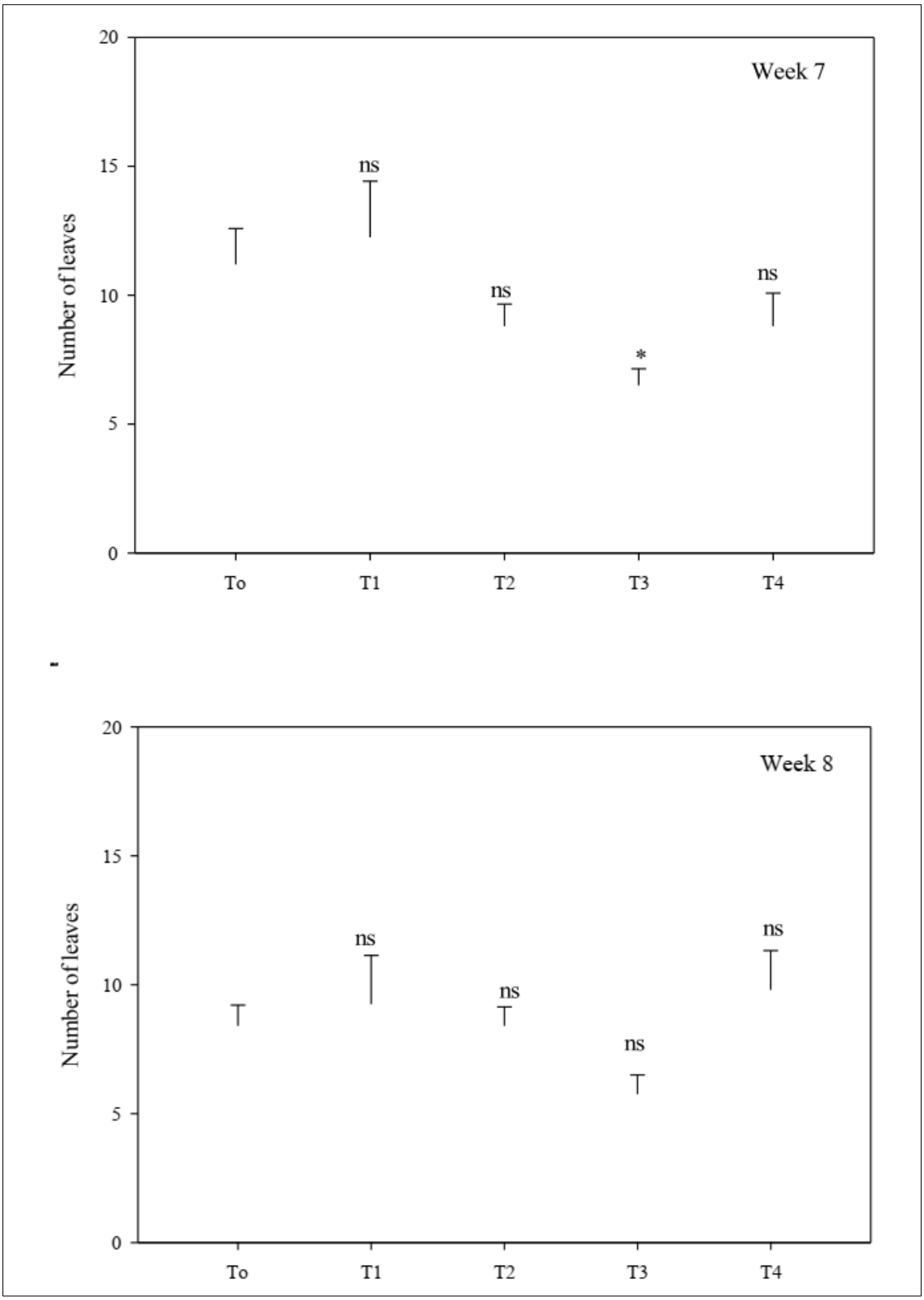


Figure 4.2.2.4: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 7 and during week 8.

The number of leaves during week 9th ranged from 6 to 12 in T4 and T0 respectively. The treatment T1,T2, T3 and T4 showing non-significant difference with control group T0. During week 10th number of leaves ranged from 6 to 12 in T4 and T0 respectively and all the treatments were showing non-significant difference with T0 (control).

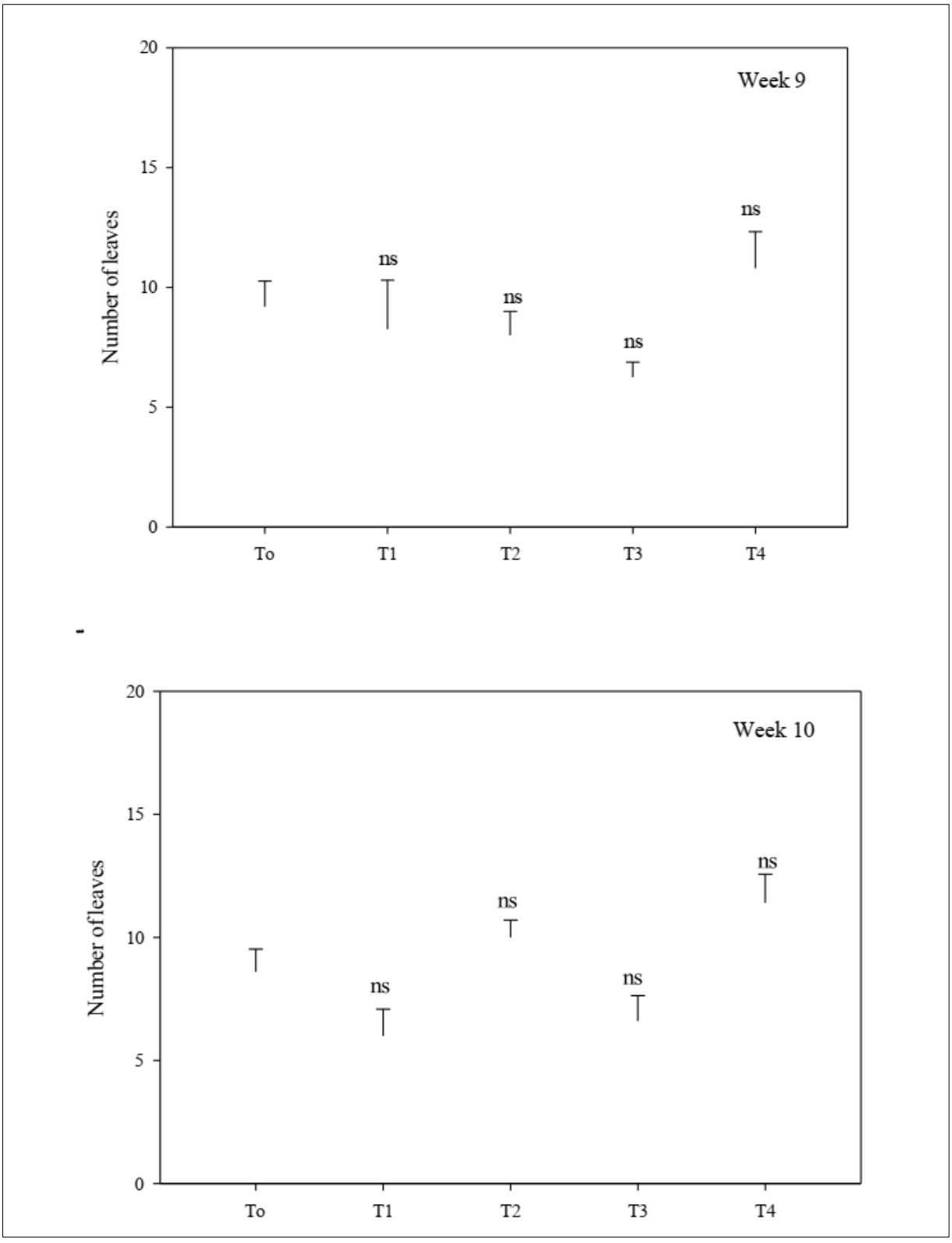


Figure 4.2.2.5: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 9 and during week 10.

The number of leaves during week 11th ranged from 8 to 11 in T4 and T0 respectively. The treatment T1, T2, T3 and T4 showing non-significant difference with control group T0. During week 12th number of leaves ranged from 7 to 12 in T4 and T0 respectively and T1, T2, and T4 was showing non-significant difference with T0 (control). while treatment T3 was showing significant difference with T0 (control).

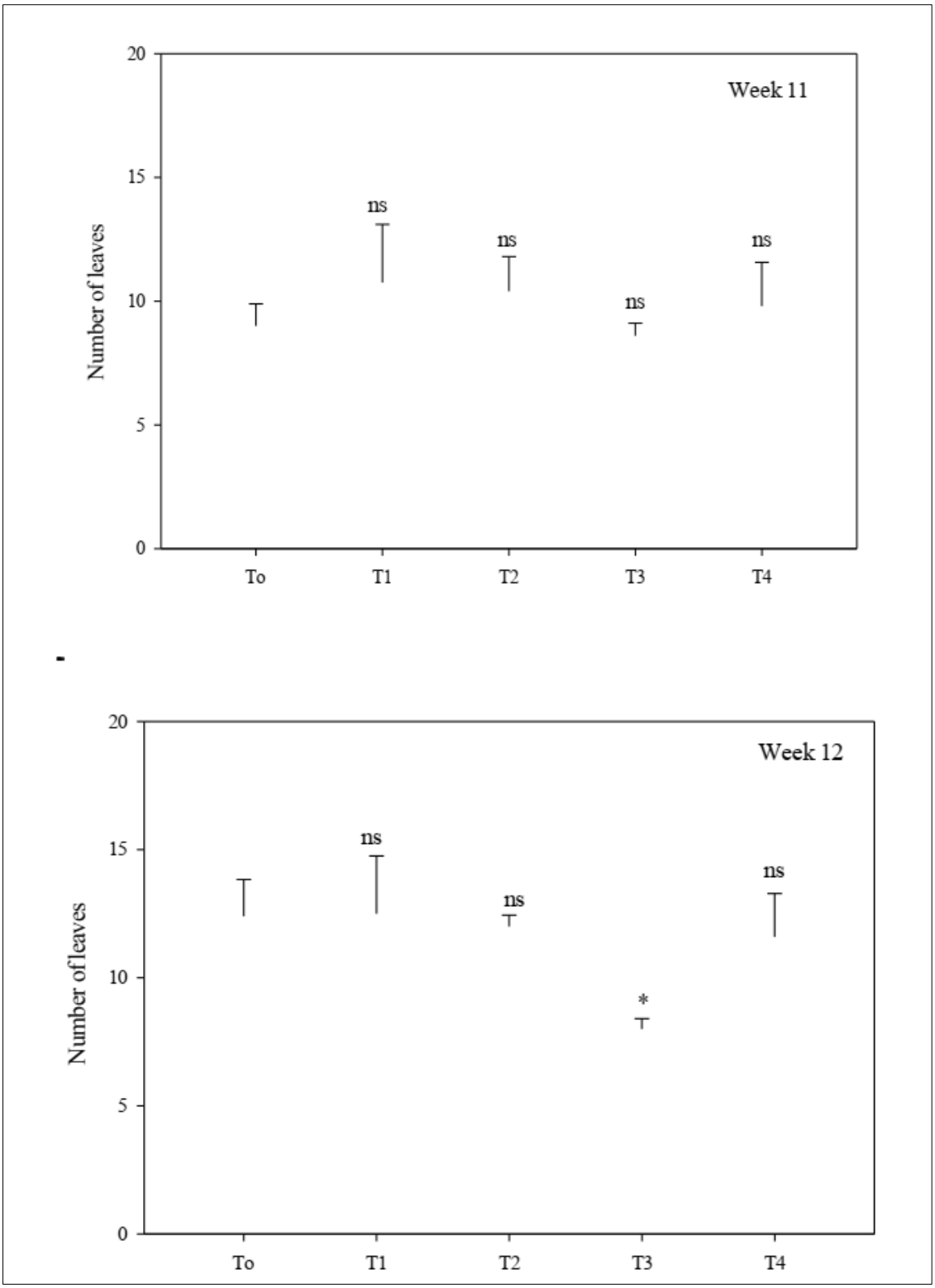


Figure 4.2.2.6: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 11 and during week 12.

The number of leaves during week 13th ranged from 5 to 11 in T4 and T0 respectively. The treatment T1, T2, and T4 showing non-significant difference while treatment T3 was showing significant difference with control group T0. During week 14th number of leaves ranged from 5 to 11 in T4 and T0 respectively and T1, T2, and T4 was showing non-significant difference with T0 (control). While treatment T3 was showing significant difference with T0 (control).

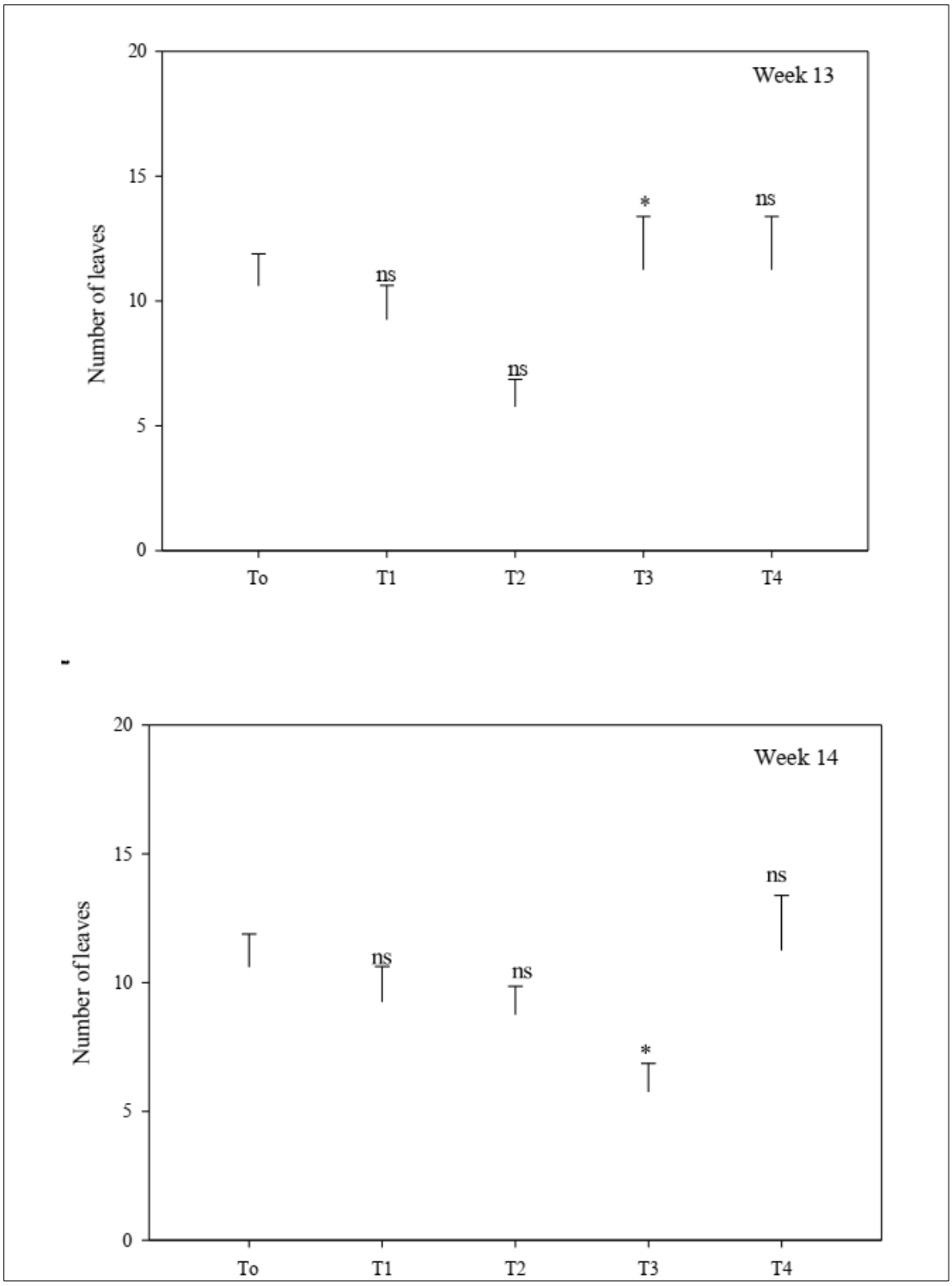


Figure 4.2.2.7: Showing the mean number of leaves *Oryza sativa* Super Kainat ± SE during week 13, and during week 14.

4.2.8. Lithium (Li^+) Uptake by Shoots and Leaves of Oryza Sativa cv. Super Kainat

Li^+ in shoots ranged from 0.3 to 1.3 mg/kg in T4 and T0 respectively. T1 treatment showing non-significant difference while others treatments were showing significant difference with T0 (control) group. Meanwhile Li^+ in Leaves ranged from 0 to 4 mg/kg in T4 and T0 respectively. All treatments were showing significant difference with T0 (control) in shoots the uptake of lithium level was maximum in T2 as compare to other treatments and minimum in T1. In Leaves, among all treatments T3 had maximum lithium uptake and minimum in T1.

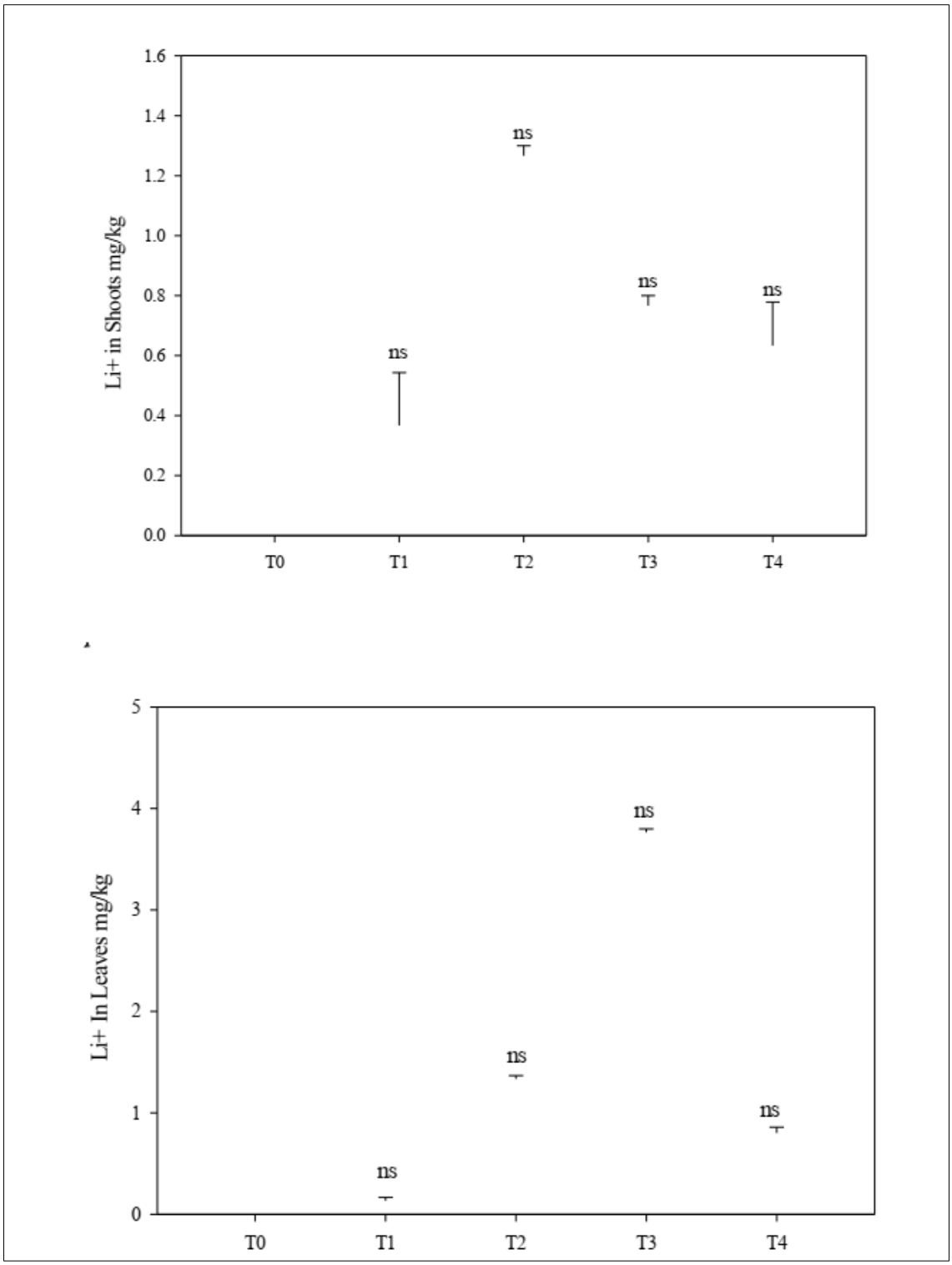
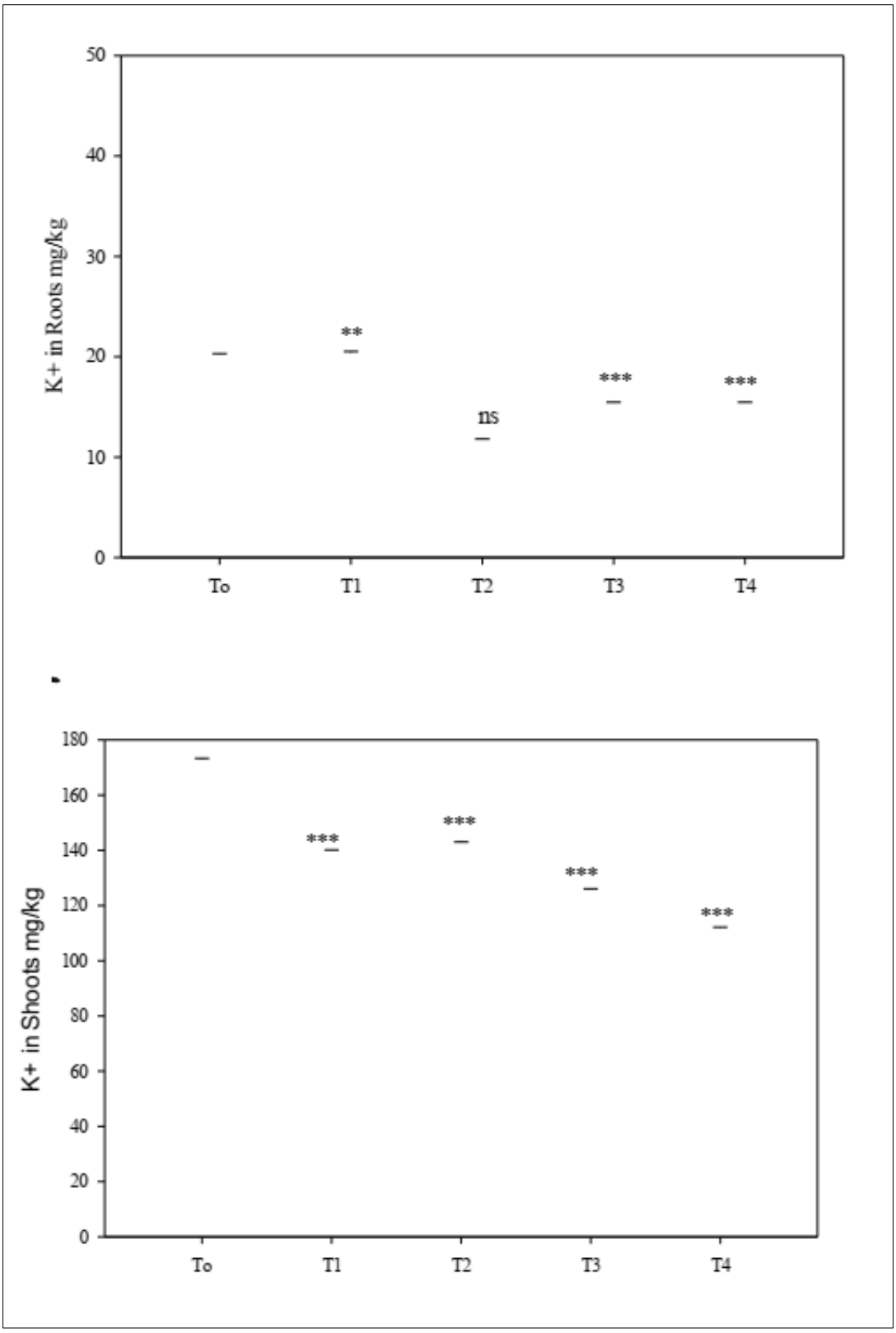


Fig. 4.8: Showing uptake of Li^+ by Shoots and Leaves in rice plant.

4.3. Uptake of Potassium in Plants Treated with NaCl in Roots, Shoots, Leaves and Seeds:

The concentration of potassium in roots of the plants treated with sodium ranged from 10 g kg-1 to 20 g kg-1 in T4 to T0 respectively. All treatments were showing significant difference except T2 with T0(control) group. In shoots potassium concentration ranged from 110g kg-1 to 170g kg-1 in T4 to T1 respectively. All treatments were showing significant difference with T0 control group. In Leaves potassium uptake ranged from 70g kg-1 to 90g kg-1 from T4 to T0 respectively. All treatments were showing significant difference with T0 control group. Meanwhile in seeds potassium concerned ranged from 2g kg-1 to 4 g kg-from T4 to T0 respectivly All treatments were showing significant difference with T0 control group.


K+ in Roots mg/kg
50
40
30
20
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ns
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To
T1
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K+ in Shoots mg/kg
180
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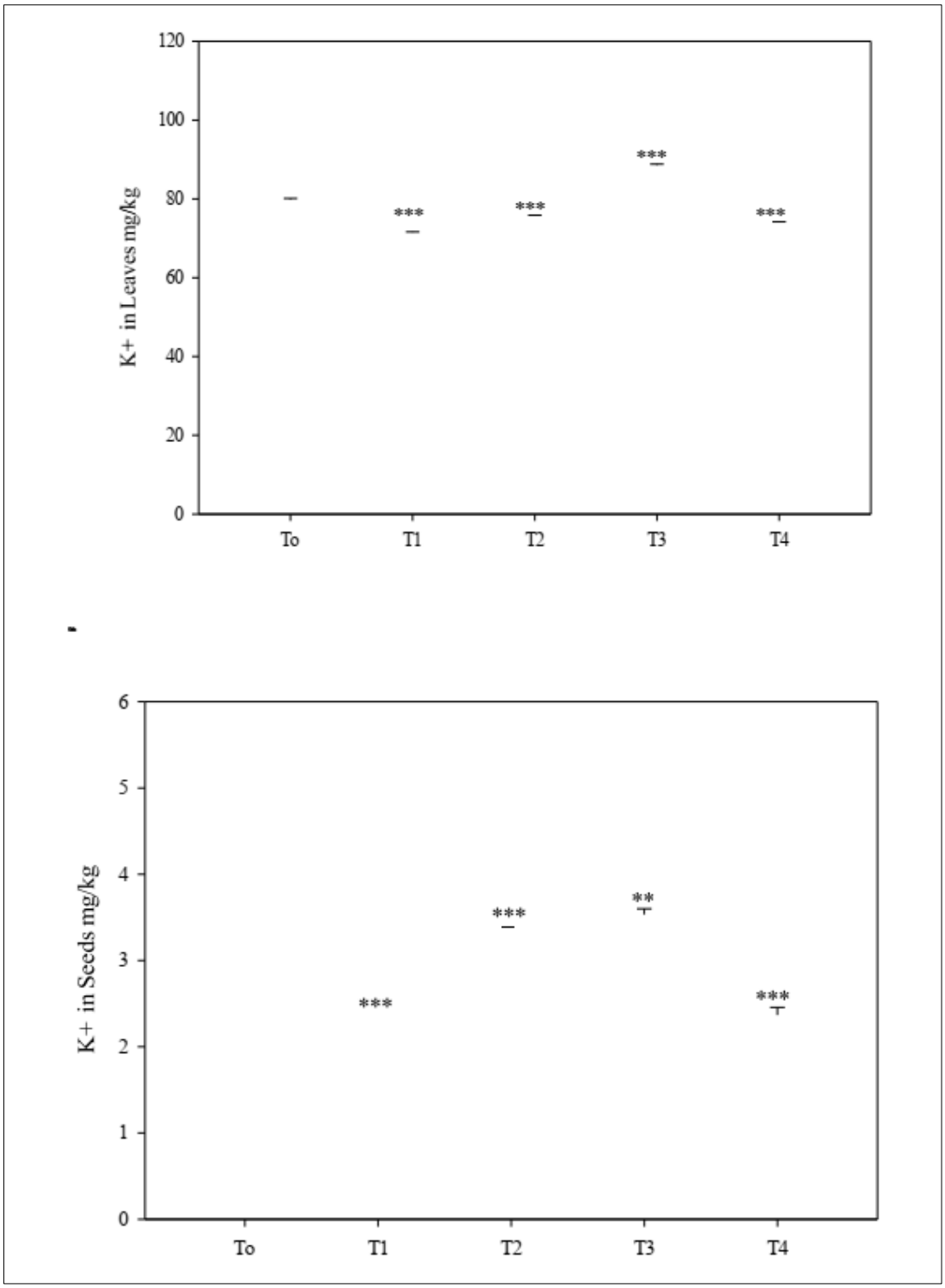


Fig. 4.3: Showing uptake of k^+ by shoots, leaves, roots and seeds in (sodium) in *Oryza sativa* L.cv. super kaina

4.4. Uptake of Potassium in Plants Treated with LiCl in Roots, Shoots, Leaves and Seeds:

The concentration of potassium in roots of the plants treated with Lithium ranged from 10 g kg-1 to 60 g kg-1 in T4 to T0 respectively. All treatments were showing significant difference with T0(control) group. In shoots potassium concentration ranged from 110g kg-1 to 210g kg-1 in T4 to T1 respectively. All treatments were showing significant difference with T0 control group. In Leaves potassium uptake ranged from 60g kg-1 to 130g kg-1 from T4 to T0 respectively. All treatments were showing significant difference with T0 control group. Meanwhile in seeds potassium concerned ranged from 4g kg-1 to 7 g kg- from T4 to T0 respecting. All treatments were showing significant difference with T0 control group.

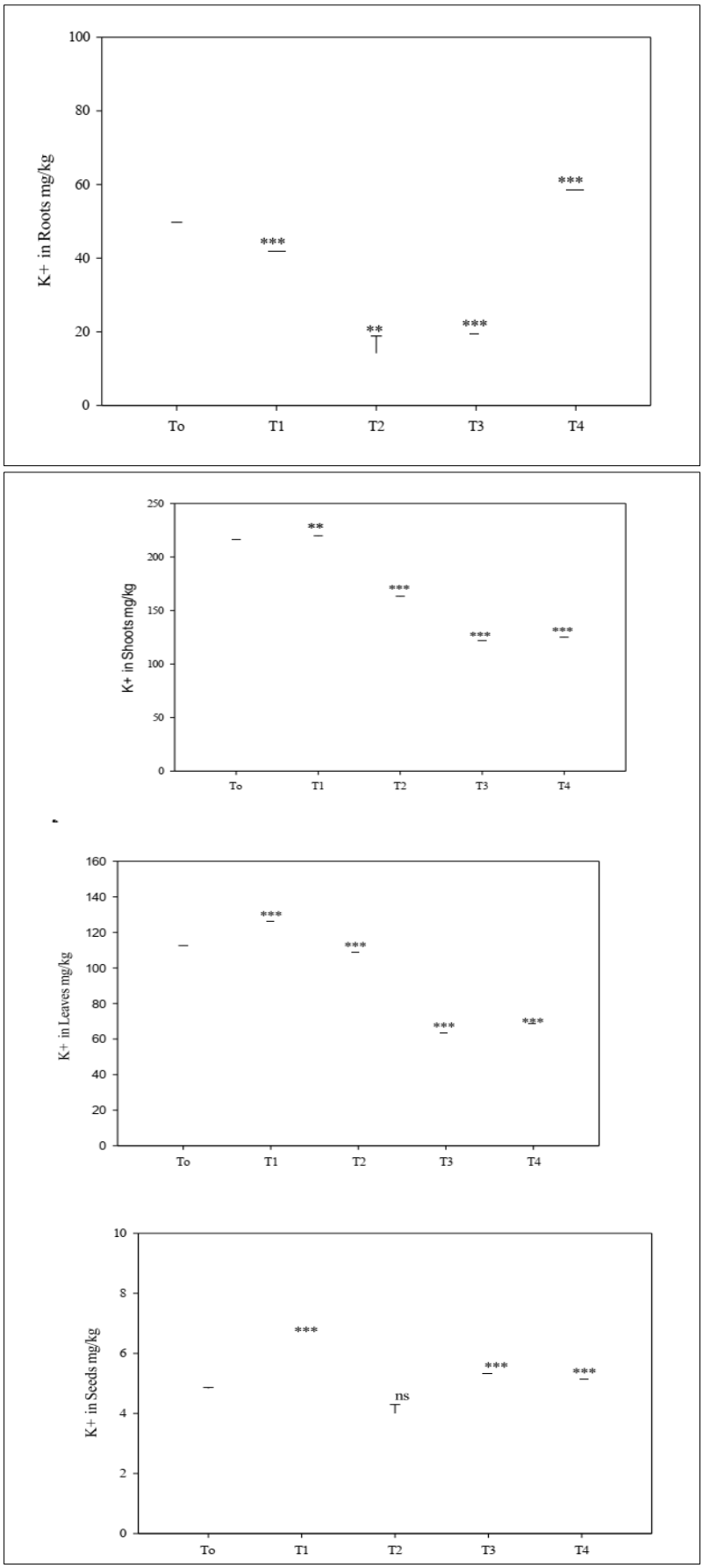


Fig. 4.4: Showing uptake of k^+ by shoots, leaves, roots and seeds in (Lithium) in rice plant

4.5. Fresh Whole Plant Weight (g) of Each Replicate of Oryza Sativa cv. Super Kainat Treated with Sodium and Lithium

Fresh whole plant weight of rice plant of sodium ranged from 2.5 to 5.5g in T4 and T0 respectively. All treatments showing non-significant difference with control group. Fresh whole plant weight (g) of Lithium ranged from 2 to 6g in T4 and T0 respectively. Treatments T1 and T3 were showing non-significant difference with control group while T2 and T4 were showing significant difference with T0 control group.

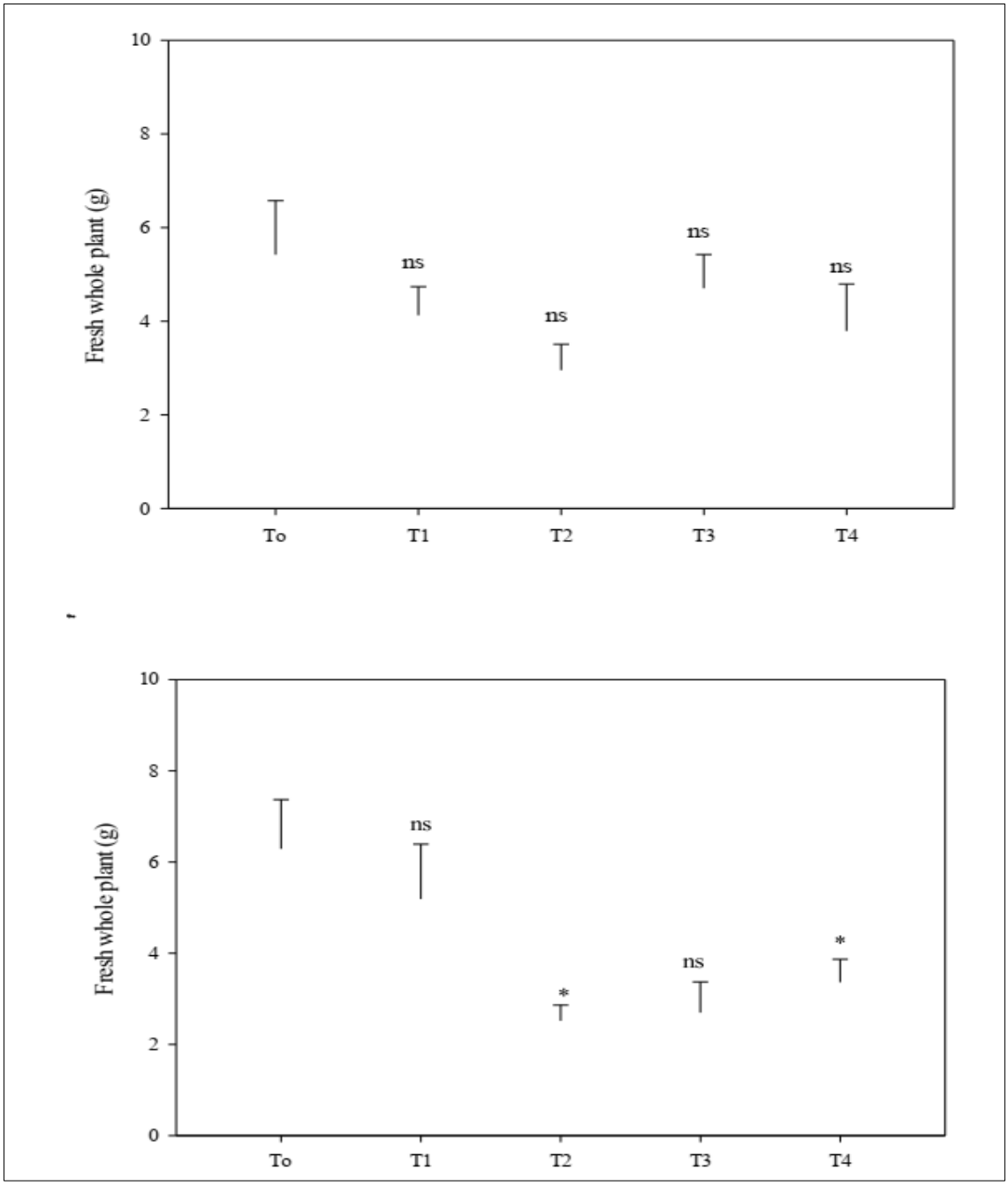


Figure 4.5: Showing the mean fresh weight ± SE in Oryza sativa cv. Super Kainat ns indicates the non-significant difference.

4.6. Fresh Weight (g) of Root, Shoot and Grain of Oryza Sativa cv. Super Kainat in Sodium:

Fresh weight of roots ranged from 0.6g to 1.2g in T4 and T0 respectively. All treatments showing non-significant difference with T0 (control). The fresh weight of shoot ranged from 2.5 to 3.2g in T4 and T0 respectively. All treatments were showing non-significant difference. The fresh weight of grain ranged from 0.5g to 0.5g in T4 and T0 respectively. All treatments were showing non-significant difference with control group.

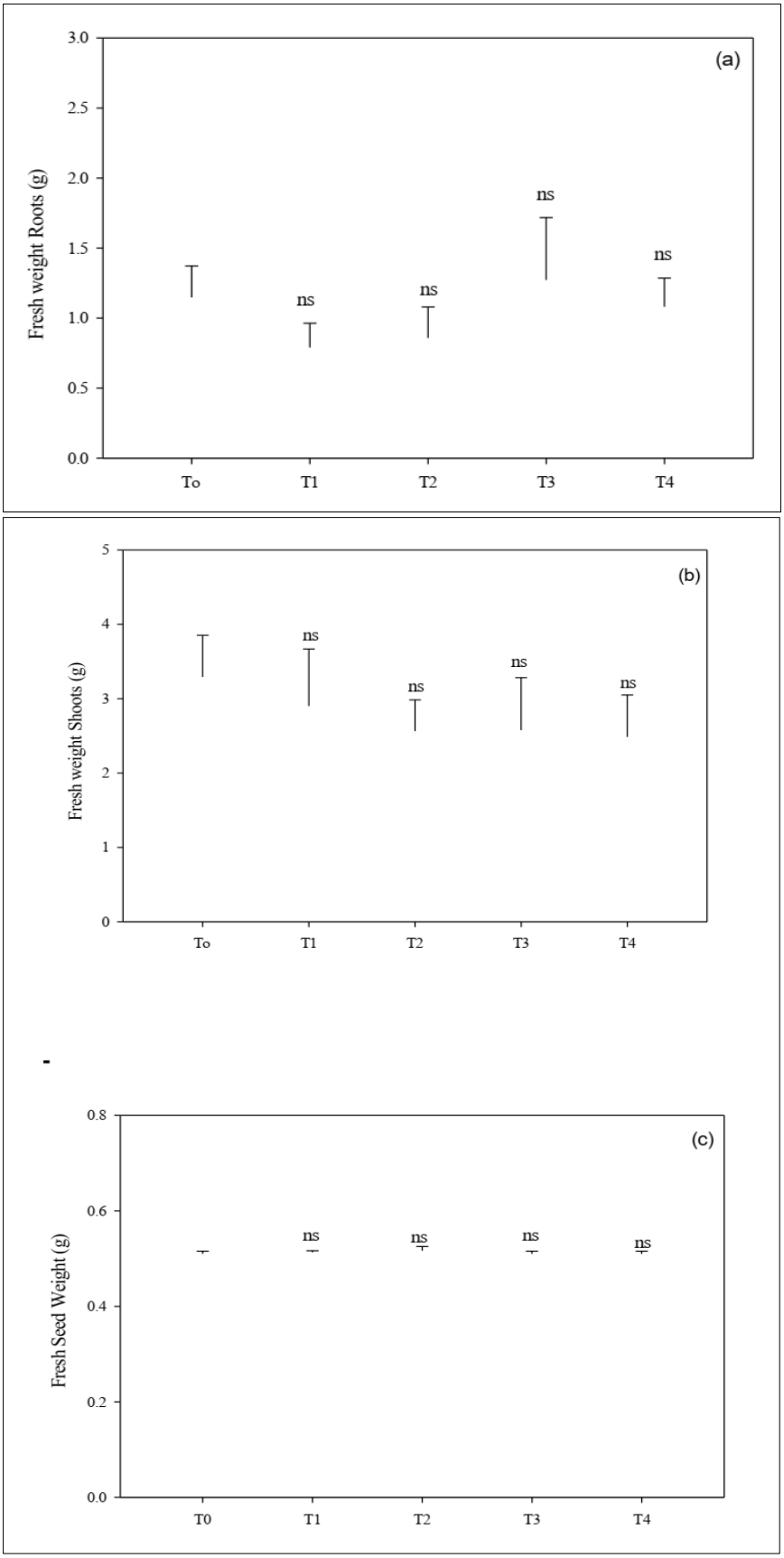


Figure 4.6: Showing the mean fresh weight of root, panel (a), shoot, panel (b), grain, panel (c) ± SE in *Oryza sativa* Super Kainat ns indicates the non-significant difference

4.7. Fresh Weight (g) of Root, Shoot and Grain of Oryza Sativa cv. Super Kainat in Lithium:

Fresh weight of roots ranged from 0.5g to 1.4g in T4 and T0 respectively. All treatments showing significant difference except T1 treatment with T0 (control). The fresh weight of shoot ranged from 1.5 to 2.5g in T4 and T0 respectively. All treatments were showing non-significant difference except T2 treatment with control group. The fresh weight of grain ranged from 0.5g to 0.5g in T4 and T0 respectively. All treatments were showing non-significant difference with control group.

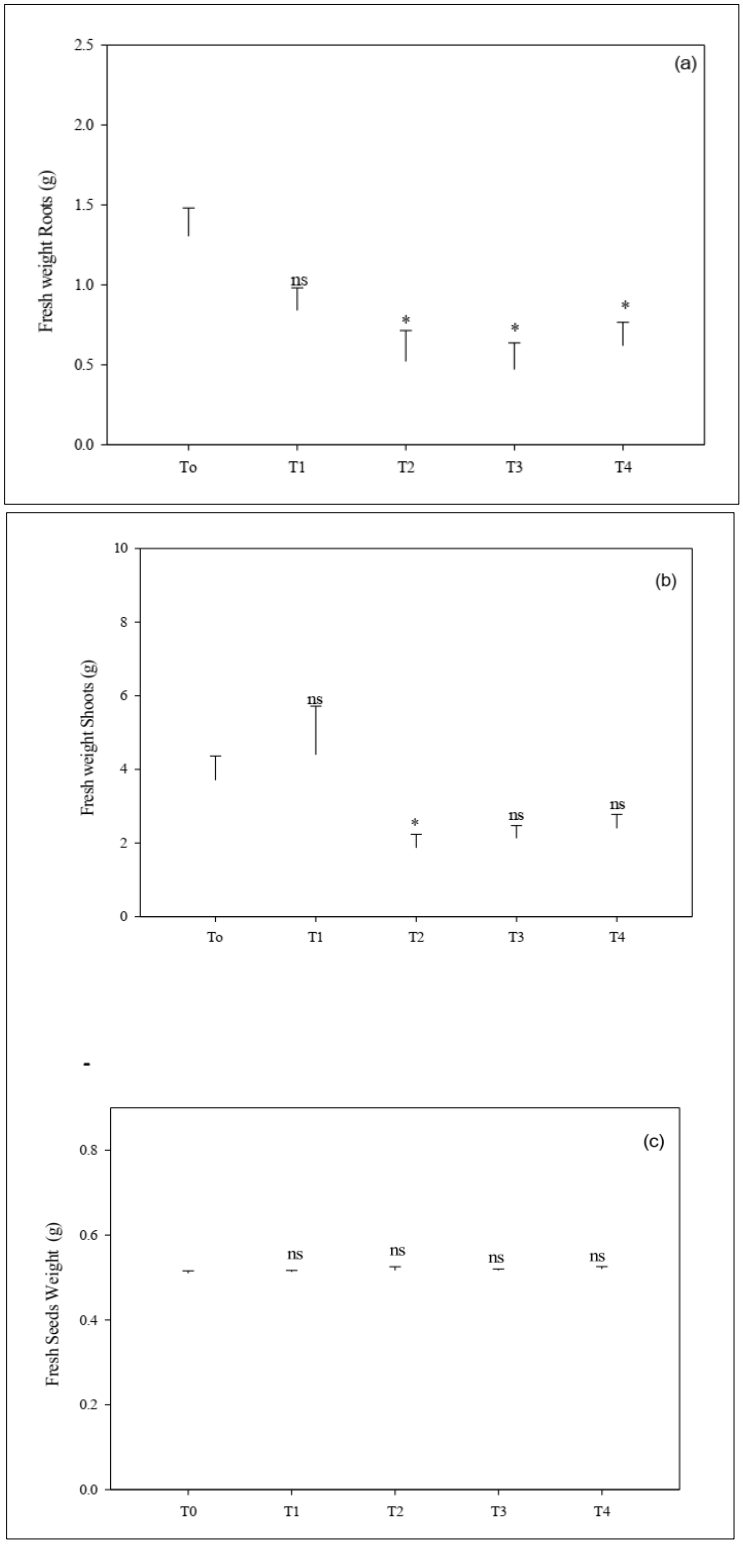


Figure 4.7: Showing the mean fresh weight of root, panel (a), shoot, panel (b), grain, panel (c) ± SE in *Oryza sativa* Super Kainat ns indicates the non-significant difference

4.8. Dry Weight of Roots Shoots Leaves and Grains in Sodium:

Dry weight of roots ranged from 1.0g to 1.02g in T4 and T0 respectively. Treatments T1 and T2 showing significant difference while treatments T2 and T3 were showing non- significant difference with T0 (control). The Dry weight of shoots ranged from 1.0 to 1.02g in T4 and T0 respectively. All treatments were showing significant difference. The fresh weight of leaves ranged from 1.0g to 1.01g in T4 and T0 respectively. Treatments T1,T2 and T3 were showing non-significant difference while T4 showed significant difference with control group. In grains the dry weight ranged from 1.0g to 1.01 g in T4 to T0 treatments T1 and T3 were showing significant difference while treatments T2 and T4 were showing non-significant difference with T0 control group.

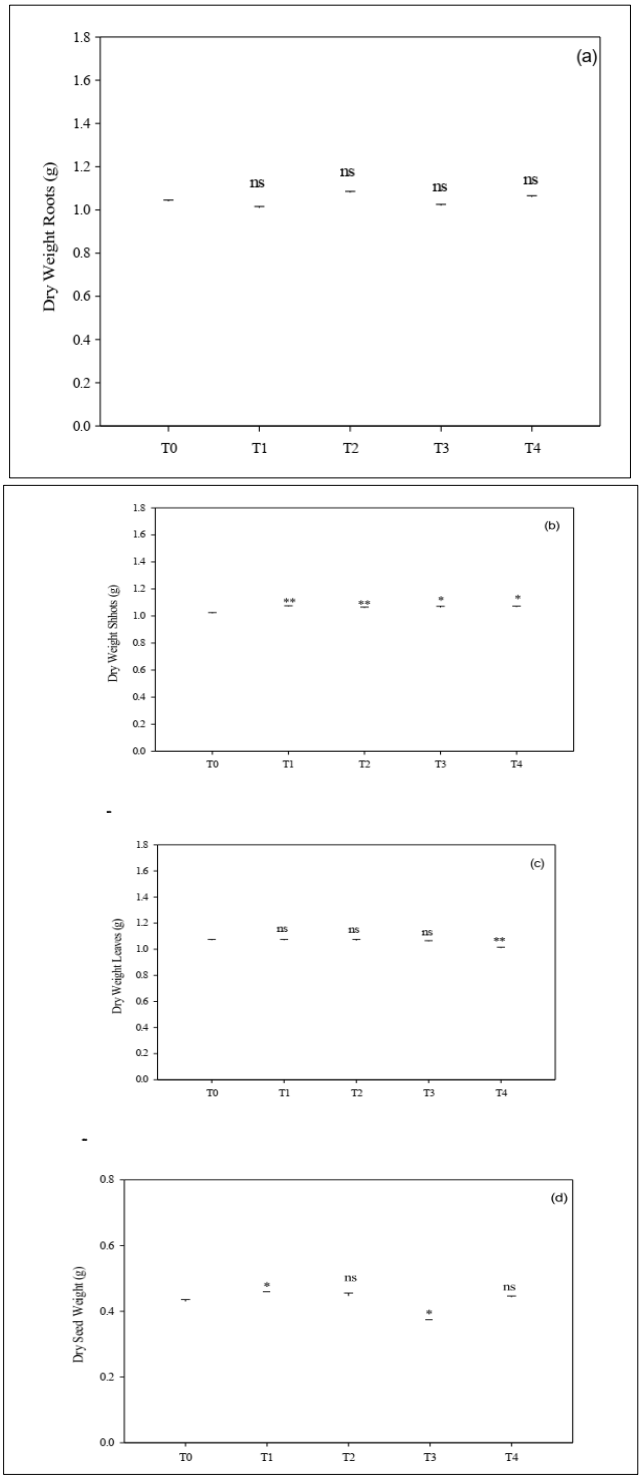
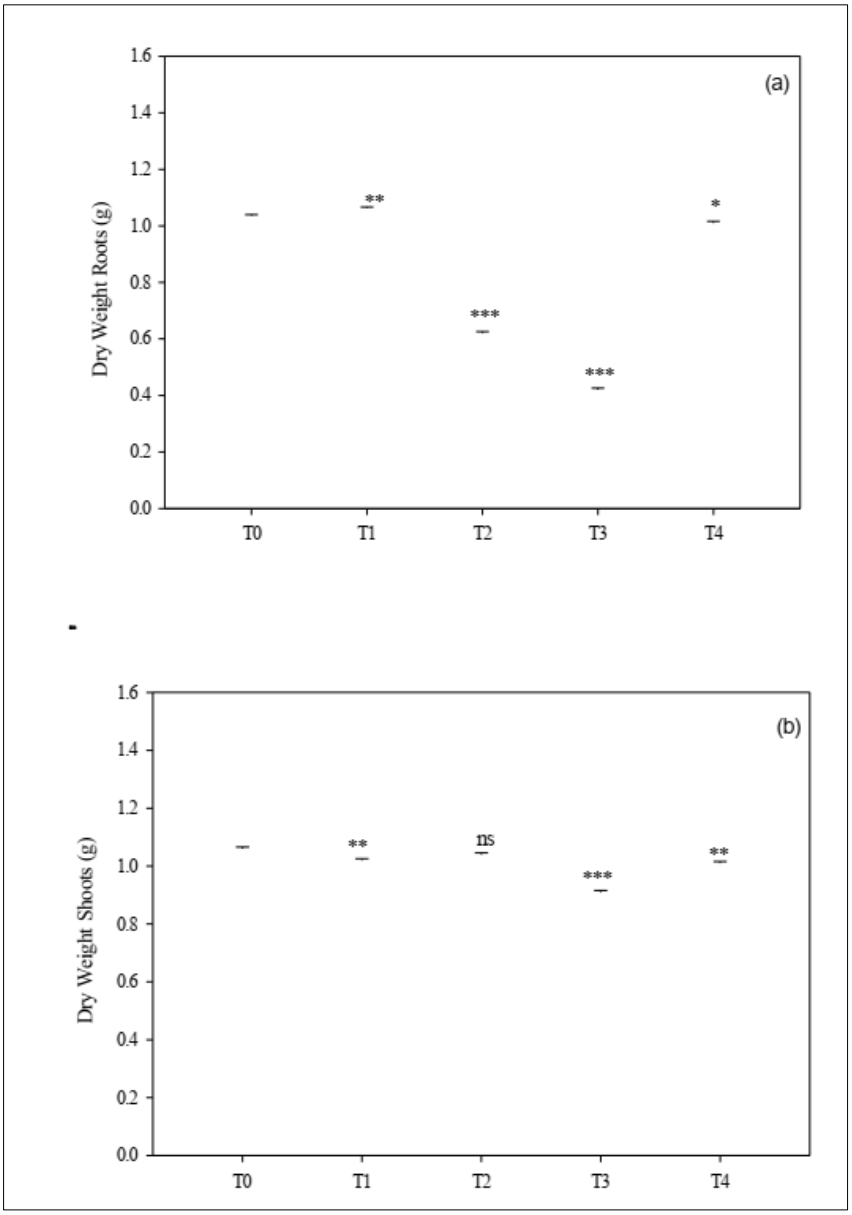


Figure 4.8: Showing the mean dry weight of root, panel (a), shoot, panel (b) leaves, panel (c) and seeds panel (d) ± SE in *Oryza sativa* Super kainat ns indicates the non-significant difference

4.9. Dry Weight (g) of Root, Shoot, Leaves and Grains of *Oryza Sativa* cv. Super kainat in Lithium:

Dry weight of roots ranged from 0.4g to 1.0g in T4 and T0 respectively. All Treatments were showing significant difference with T0 (control). The Dry weight of shoots ranged from 0.9 to 1.0g in T4 and T0 respectively. All treatments were showing significant difference except T2 treatment with control group. The Dry weight of leaves ranged from 1.01g to 1.02g in T4 and T0 respectively. All Treatments were showing significant difference with control group. In grains the dry weight ranged from 0.4g to 0.5 g in T4 to T0. Treatments T1, T2 and T4 were showing non-significant difference while treatments T3 showing significant difference with control group.



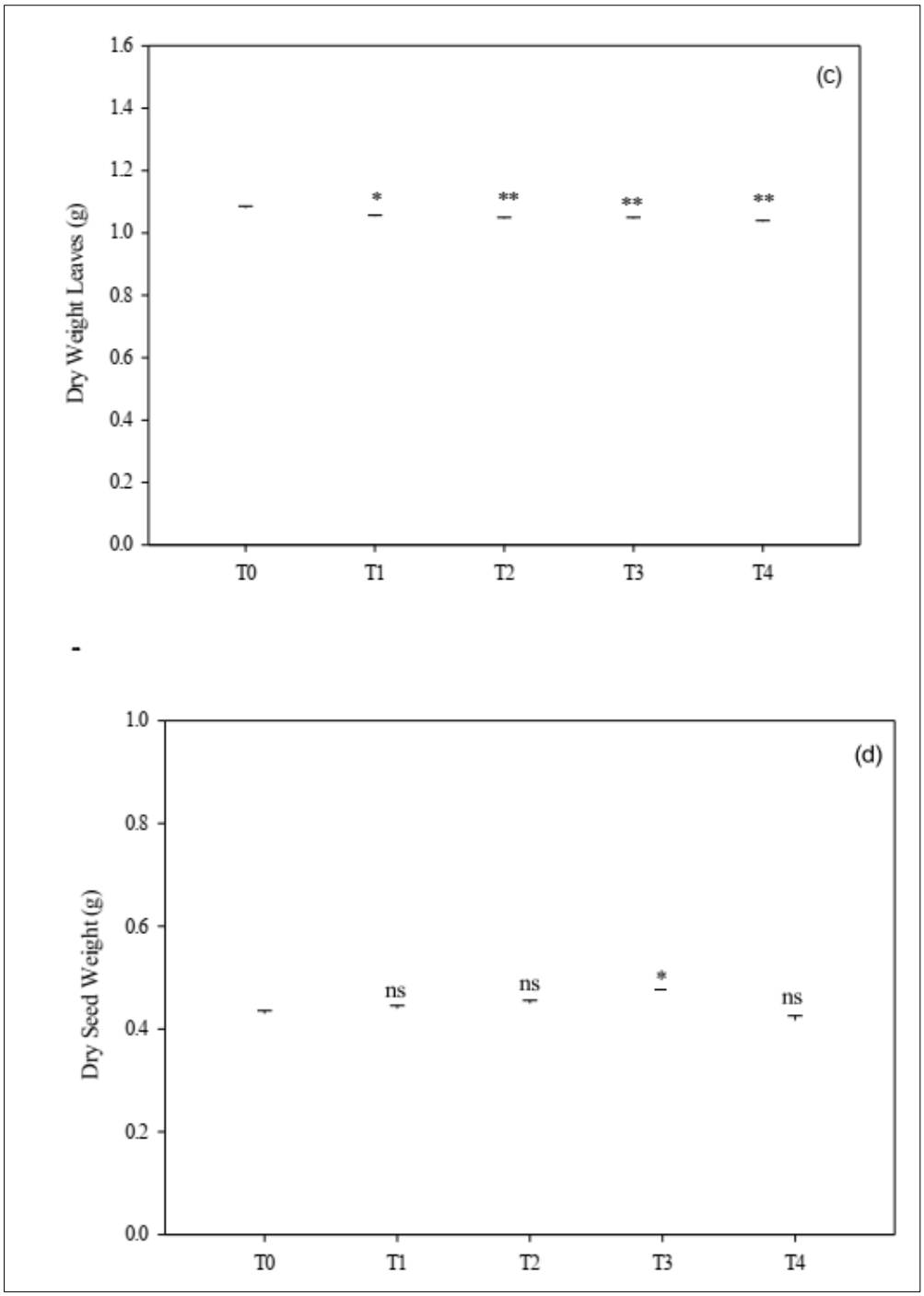


Figure 4.9: Showing the mean dry weight of root, panel (a), shoot, panel (b) leaves, panel (c) and grains panel (d) ± SE in *Oryza sativa* Super Kainat ns indicates the non-significant difference.

4.10. Chlorophyll Content of Lithium and Sodium:

The chlorophyll content of Lithium ranged from 25 to 32 in T4 and T0 respectively. All treatments were showing significant difference while T4 was showing non-significant difference with control group (T0). As seen in below graph, the chlorophyll content high in T2 as compare to other treatments and low in T0 while other treatments showed moderate range under salt stress. The chlorophyll content of Sodium ranged from 28 to 39 in T4 and T0 respectively. All treatments were showing significant difference while T3 was showing non-significant difference with control group (T0). As seen in below graph, the chlorophyll content high in T0 as compare to other treatments and low in T1 and T2 while other treatments showed moderate range under salt stress.

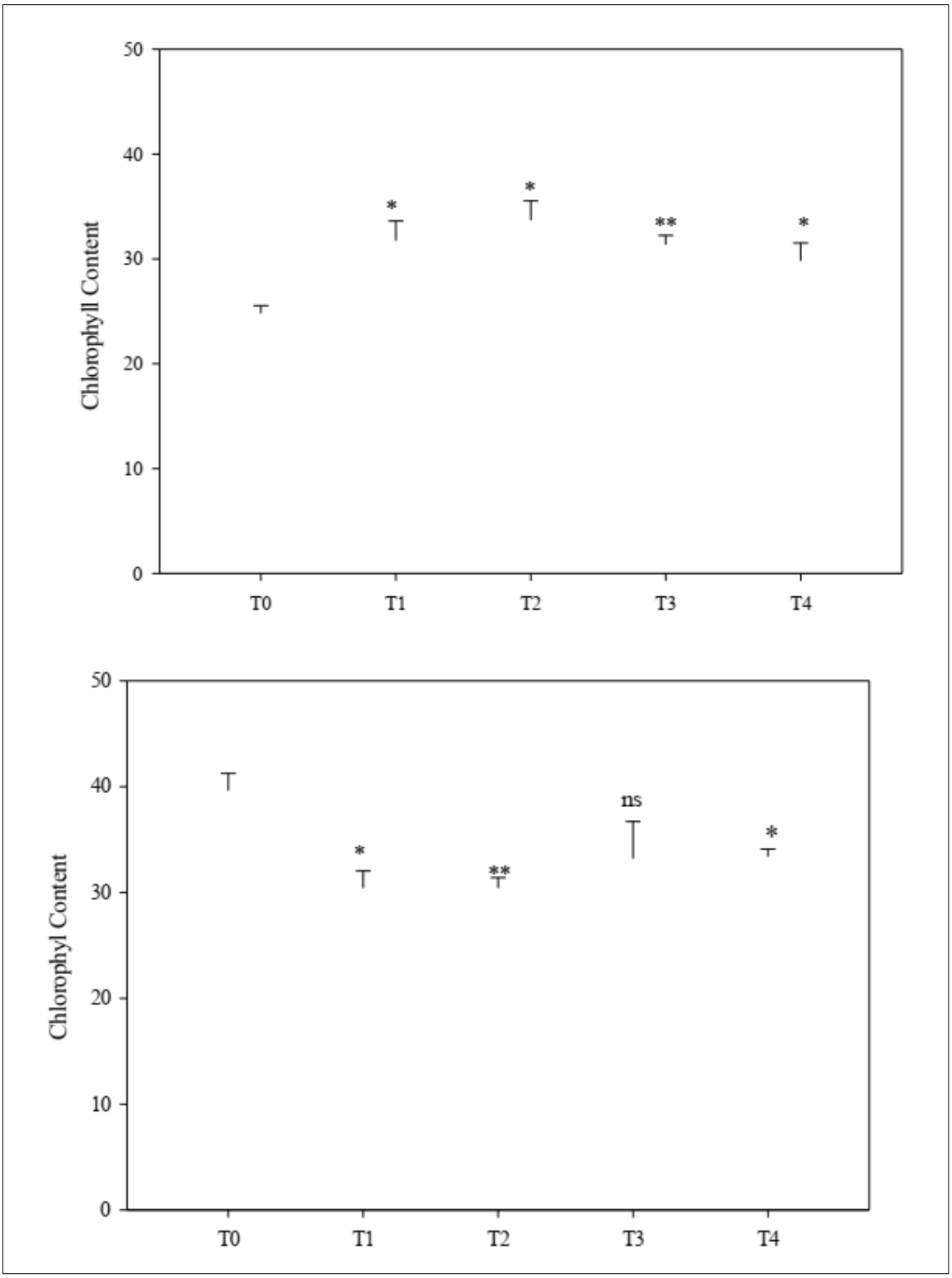


Fig. 4.10: Showing the chlorophyll content in leaf of each replicates of Sodium and Lithium.

4.11. Dry whole plant weight Sodium and Lithium:

Dry whole plant weight of rice plant of sodium ranged from 3.9 to 2.5g in T4 and T0 respectively. All treatments showing significant difference except T1 with control group. Fresh whole plant weight (g) of Lithium ranged from 4.5 to 0.5g in T4 and T0 respectively. All treatments showing non- significant difference except T1 with control group.

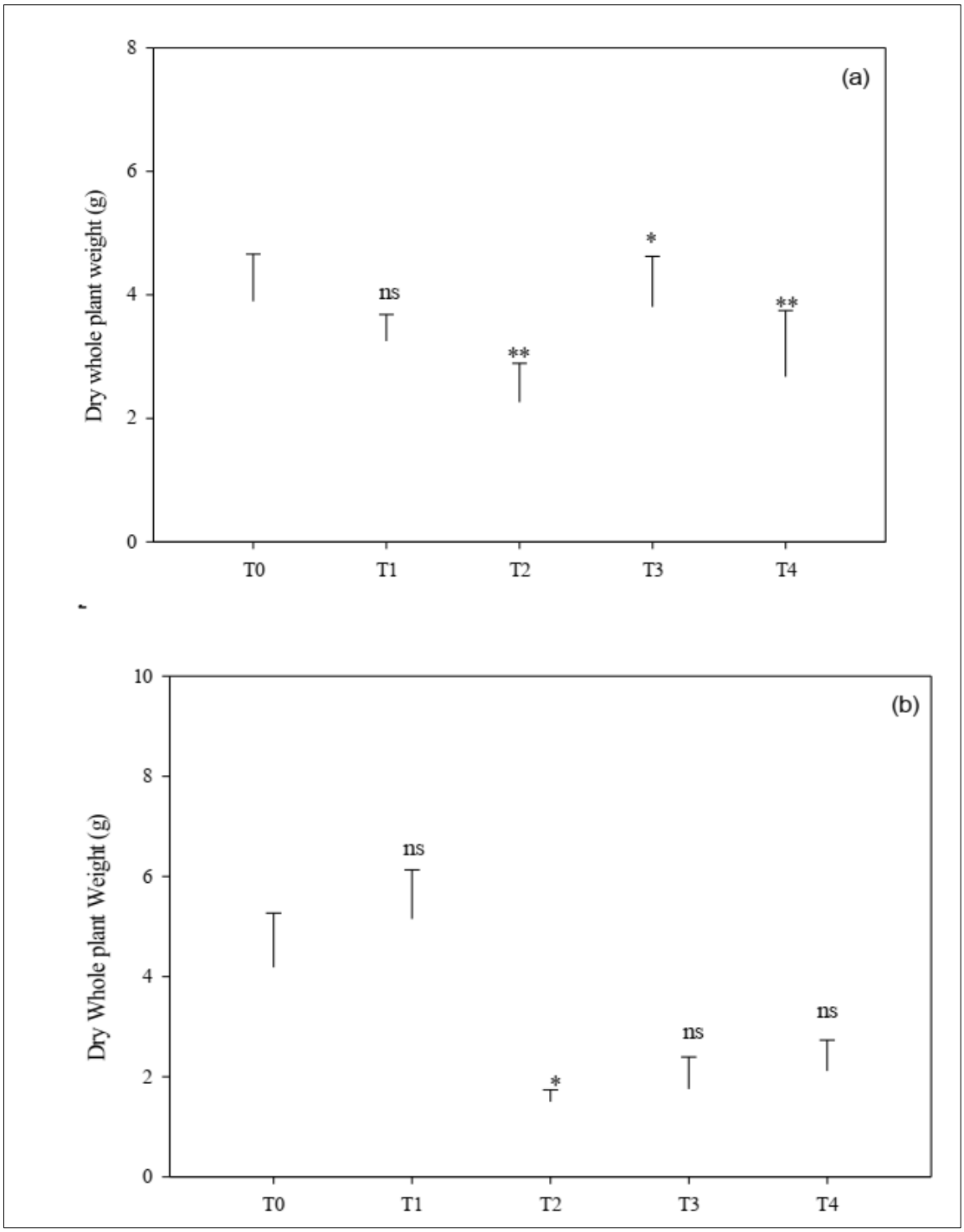


Figure 4.11: Showing the mean dry weight of Whole Plant panel (a), panel (b) ± SE in *Oryza sativa* Super Kainat ns indicates the non-significant difference.

4.12. Physiological Traits of Oryza Sativa cv. super Kainat during Sunny Day, Such as Rate of Photosynthesis (A) Stomatal Conductance (gs) and rate of Transpiration (E) in Lithium:

Rate of photosynthesis ranged from 0.9 to 40 µmol.m-2 s-1 in T4 and T0 respectively. All treatments were showing significant difference except T4 with control group. Stomatal conductance ranged from 0.02 to 1.7 µmol.m2. s-1in T4 and T0 respectively. The treatments T2, T3 andT4 showing significant difference while T1 was showing non- significant difference with T0 (control). The rate of transpiration ranged from 0.03 to 0.43 mmol.m2. s-1 in T4 and T0 respectively. The treatments T1, T2, T3, T4 were showing significant difference with control group.

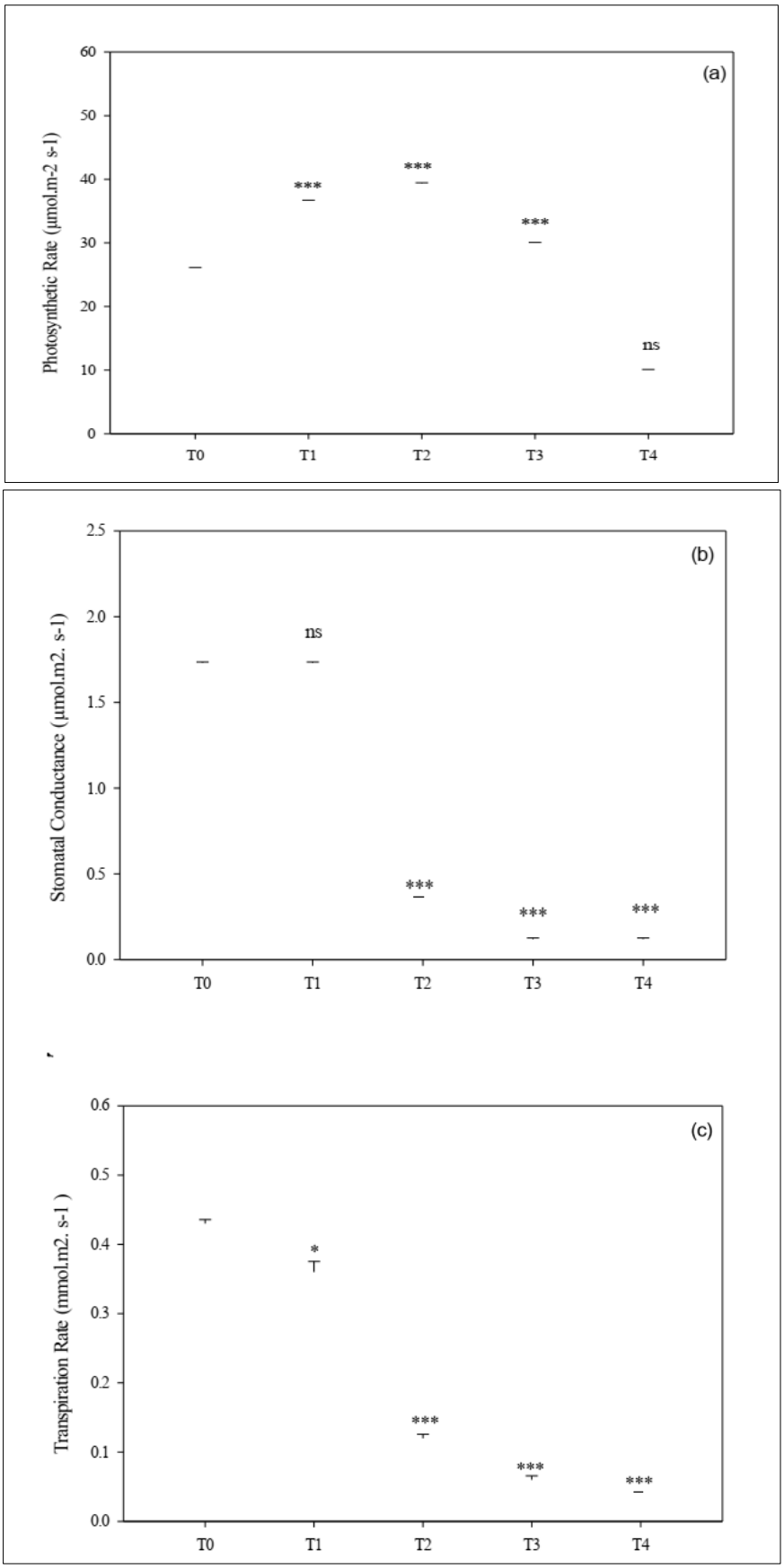


Figure 4.12: Showing the rate of transpiration (E) during sunny day, panel (a), rate of photosynthesis during sunny day, panel (b) and Stomatal Conductance during sunny day, panel (c)

4.13. Physiological Traits of Oryza Sativa cv. Super Kainat during Sunny Day, Such as Rate of Photosynthesis (A) Stomatal Conductance (gs) and Rate of Transpiration (E) in Sodium:

Rate of photosynthesis ranged from 0.4 to 25 µmol.m-2 s-1 in T4 and T0 respectively. All treatments were showing significant difference. Stomatal conductance ranged from 0.03 to 0.7 µmol.m2. s-1in T4 and T0 respectively. The treatments T1, T2, T3, T4 showing significant difference with T0 (control). The rate of transpiration ranged from 0.23 to 0.4 mmol.m2. s-1in T4 and T0 respectively. The treatments T1, T2, T3, T4 were showing significant difference with control group**.**

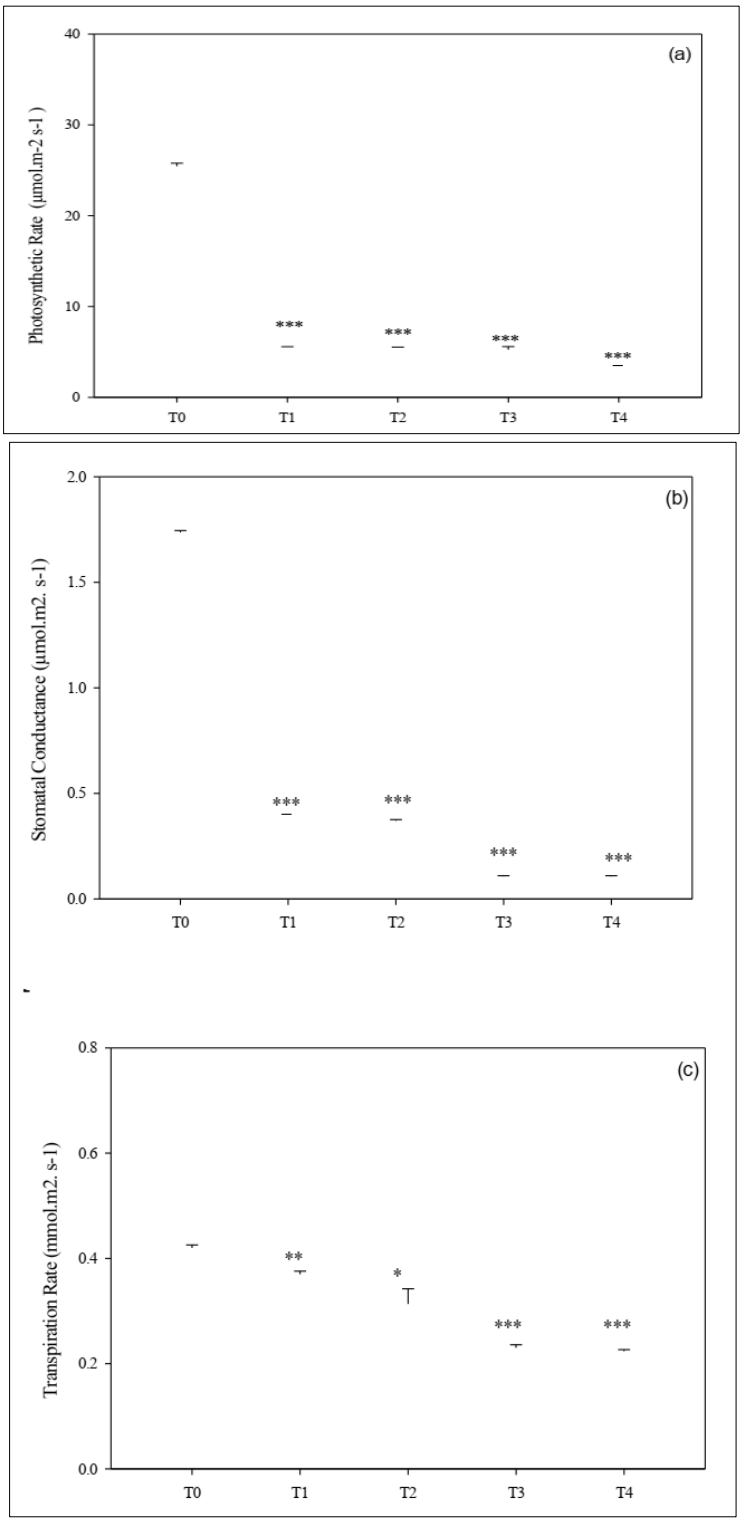


Figure 4.13: Showing the rate of transpiration (E) during sunny day, panel (a), rate of photosynthesis during sunny day, panel (b) and panel, (c) Stomaal Conductance (gs)

5. CONCLUSION

This study reveals that *Oryza sativa* L. cv. Super Kainat can withstand NaCl concentrations of up to 60 mM L^{-1} and LiCl up to 4 ppm. It had no detrimental consequences during its early stages of development. However, after four weeks, there was a considerable decline in plant height, number of leaves, and plant biomass. The fresh and dry weight of the plant's root, shoots, and grains were considerably affected by NaCl (15 mM,30 mM,45 mM and 60 mM) and LiCl (1,2,3 and 4 ppm) concentrations at various levels. K^+ uptake is lower in roots, Na^+ uptake is higher, and Li^+ uptake is likewise higher in roots. However, the K^+ uptake in grains is greater than the Na+ and Li+ uptake in grains. The absorption of Na^+ and Li+ in rice of super kainat grains is significantly lower.

REFERENCES

- Abbas, M.K., S. Ali, H.H. Hasan, and R.H. Ghal. 2012. Salt Tolerance Study of Six Cultivars of Rice (*Oryza sativa* L.) During Germination and Early Seedling Growth. *J. of Agri. Sci*., 5(1).
- Abdelraheem, A.N. Esmaeili, M.A. O'Connell and J. Zhang. 2019. Progress and perspective on drought and salt stress tolerance in cotton. *Industrial Crops and Product.,* 130: 118-129.
- Acosta-Motos, J.R., M. Ortuño, A. Bernal-Vicente, P. Díaz-Vivancos, M.J. Sánchez- Blanco and J.A. Hernández. 2017. Plant responses to salt stress. Adaptive mechanisms. *Agronomy*., 7(1):18.
- Adrees, M., S. Ali, M. Rizwan, M.Z.U. Rehman, M. Ibrahim, F. Abbas, M. Farid, M.F Qayyum, and M. Irshad. 2015. Mechanisms of silicon-mediated alleviation of heavy metal toxicity in plants. A review. *Ecotoxicology and Environmental Safety*., 119: 186-197.
- Ahmad, P., G. Nabi, and M. Ashraf. 2011. Cadmium-induced oxidative damage in mustard [*Brassica juncea* (L.) Czern. & Coss.] plants can be alleviated by salicylic acid. *South African Journal of Botany*., 77(1): 36-44.
- Ahmad, P., M. Sarwat, N.A. Bhat, M.R. Wani, A. Gul, and L.P. Tran. 2015. Alleviation of Cadmium Toxicity in *Brassica juncea* L. (Czern. & Coss.) by Calcium Application Involves Various Physiological and Biochemical Strategies., 10(1):011-4571.
- Ali, U., T. Shar, R. Ahmad, M. Khatoon, M.A. Khaskheli, A.H. Laghari and A.J. Leghari. 2021. Salinity stress–a threat to rice production breeding strategies to develop salinity tolerance in plants. *Mehrgarh Journal of Sciences and Technology*., 1(1):13-17.
- *Annual Review of Plant Biology*., 64: 451-476.
- Asch, F., M. Dingkuhn and K. Dorffling. 2000. Salinity increases CO2 assimilation but reduces growth in field-grown, irrigated rice. *Plant and Soil*., 218: 1-10.
- Aslam, M.M., Rashid, M.a.R. Siddiqui, M.A. Khan, M.T. Farhat, F. Yasmeen, S. Khan,
- Cakmak, I. 2005. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *Journal of Plant Nutrition and Soil Science*., 168(4): 521-530.
- Chen, T., Shabala, S.Y. Niu, Z. Chen, L. Shabala, H. Meinke, G. Venkataraman, A Pareek,
- D. Zou. 2020. Identification of a Major QTL and Candidate Gene Analysis of Salt Tolerance at the Bud Burst Stage in Rice (*Oryza sativa* L.) Using QTL-Seq and RNA-Seq. *Rice*., 13(1): 420-523
- Dekkers, B.J., L.A. Willems, G.W. Bassel, R.P. Van Bolderen-Veldkamp, W. Ligterink,
- Dioniso, SML and S. Tobita. 2000. Effects of salinity on sodium content and photosynthetic responses of rice seedlings differing in salt tolerance. *J. of Plant Physio.,* 157: 54- 8.
- Dreyer, I., and N. Uozumi. 2011. Potassium channels in plant cells. *FEBS Journal*., 278(22): 4293-4303.
- Fisher, R.A., and R. Bingham. 2010. Statistical Methods, Experimental Design, and Scientific Inference. *Oxford University Press*., 278(22): 4293-4303.
- Flowers, T.J., and T.D. Colmer. 2008. Salinity tolerance in halophytes. *New Phytologist*., 179(4): 945-963.
- Flowers, T.J., H.K. Galal and L. Bromham. 2010. Evolution of halophytes, multiple origins of salt tolerance in land plants. *Functional Plant Biology*., 37(7): 604-612.
- Ganie, S.A., K.A. Molla, R.J. Henry, K.V. Bhat and T.K. Mondal. 2019. Advances in understanding salt tolerance in rice. *Theoretical and Applied Genetics*., 132(4): 851-870.
- Gierth, M., and P. Mäser. 2007. Potassium transporters in plants-Involvement in K^+ acquisition, redistribution and homeostasis. *FEBS Letters.,* 581(12): 2348-2356.
- Gupta, M., X. Qiu, L. Wang, W. Xie, C. Zhang, L. Xiong and J.K. Zhu. 2012. KT/HAK/KUP potassium transporters gene family and their whole-life cycle expression profile in rice (*Oryza sativa* L.). *Molecular Genetics and Genomics*., 287(11): 711-722.
- Gurmani, A.R., A. Bano and M. Salim. 2006. Effect of growth regulators on growth, yield and ions accumulation of rice (*Oryza sativa* L.) under salt stress. *Pak. J. Bot*., 38(5): 1415-1424.
- H. Ji-jie and J. Qianyu. 2017. Effects of salt stress on rice growth, development characteristics, and the regulating ways, a review. *Journal of Integrative Agriculture*., 16(11): 2357-2374.
- H.W.M. Hilhorst, and L. Bentsink. 2011. Identification of reference genes for RT– QPCR expression analysis in arabidopsis and tomato seeds. *Plant and Cell Physiology*., 53(1): 28-37.
- Hafke, J.B., A. Honig, J.K. Rose and E. Loffler. 2005. Intracellular ion concentrations in growing

pollen tubes of *Lilium formosanum* change during growth, In vivo measurements using ion-selective microelectrodes. *Plant Physiology.,* 140(1): 74- 86.

- Hatamnia, A.A., N. Abbaspour, R. Darvishzadeh, F. Rahmani and R. Heidari. 2013. Effect of salt stress on growth, ion content and photosynthesis of two oriental Tobacco (*Nicotiana tabacum*) cultivars. *International Journal of Agriculture and Crop Sciences*., 6(11): 757.
- Huber, D.M., and J.B. Jones. 2013. The role of potassium in plant stress response. In Advances in Botanical Research. *Academic Press*., 68: 97-130.
- Hussain, S., J. Zhang, C. Zhong, L. Zhu, X. Cao, S. Yu, J.A. Bohr, H. JiJie and Q. Jin. 2017. Effects of salt stress on rice growth, development characteristics, and the regulating ways. A review. *Journal of Integrative Agriculture*., 16(11): 2357-2374.
- Hussain, S., Z. Jun-hua, Z. Chu, Z. Lian-feng, C. Xiao-chuang, Y. Shengmiao, A.B. James,
- I.A. Raja, S.F. Rasool, M.A. Sial and Y. Zhao. 2022. Recent Insights into Signaling Responses to Cope Drought Stress in Rice. *Rice Scienc.,* 29(2): 105-117.
- J. Xu, and M. Zhou. 2021. Molecular mechanisms of salinity tolerance in rice. *Crop Journal*., 9(3): 506-520.
- Jensen, M.K., K. Skriver and P.B. Holm. 2010. The role of plant cation transporters in potassium and sodium homeostasis. In Plant Adaptation and Phytoremediation. *Springer*., 97-120.
- Jha, U.C., A. Bohra, R. Jha and S.K. Parida. 2019. Salinity stress response and 'omics' approaches for improving salinity stress tolerance in major grain legumes. *Plant cell reports*., 38: 255-277.
- Jones, K., and W. Wang. 2010. Role of Sodium, Lithium, and Potassium in Plant Physiology. *Plant Science Reviews.,* 5: 78-92.
- *Journal of Agricultural Science.,* 7(3): 123-136.
- Kallet, R.H. 2004. How to Write the Methods Section of a Research Paper. *Respiratory Care*., 49(10): 1229-1232.
- Keller, C., M. Rizwan, J. Davidian, O.S. Pokrovsky, N. Bovet, P. Chaurand and J. Meunier. 2014. Effect of silicon on wheat seedlings (*Triticum turgidum* L.) grown in hydroponics and exposed to 0 to 30 µM Cu. *Planta.,* 241(4): 847-860.
- Khan, A., Ali, S and M. Rizwan. 2019. Sodium Compartmentalization in "Super Kainat" Rice, A Novel Perspective. *Journal of Plant Physiology*., 240: 153-160.
- Khan, M.S.A., A. Hamid, A.B. Salahuddin, A. Quasem and M.A. Karim. 2008. Effect of Sodium Chloride on Growth, Photosynthesis and Mineral Ions Accumulation of Different Types of Rice (*Oryza sativa* L.). *J. of Agro. And Crop Sci*., 179(3): 149- 161.
- Kim, Y., A.L. Khan, M. Waqas, R. Shahzad and I. Lee. 2016. Silicon-mediated mitigation of wounding stress acts by up-regulating the rice antioxidant system. *Cereal Research Communications*., 44(1): 111-121.
- Kumar, P., Choudhary, T. Halder, N.R. Prakash, V. Singh, V.T.V and K.H. Siddique. 2022. Salinity stress tolerance and omics approaches. Revisiting the progress and achievements in major cereal crops. *Heredity.,* 128(6): 497-518.
- Kumar, P., M. Choudhary, T. Halder, N.R. Prakash, V. Singh S. Sheoran, and K.H.M. Siddique. 2022. Salinity stress tolerance and omics approaches, revisiting the progress and achievements in major cereal crops. *Heredity*., 128: 497-518.
- Lei, L., Zheng, H., Bi, Y.L. Yang, H. Liu, J. Wang, J. Sun, H. Zhao, X. Li, J. Li, Y. Lai and
- Leigh, R.A., and R.G. Wyn Jones. 1984. A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell. *New Phytologist*., 97(1): 1-13.
- Linh, L.H., T.H. Linh, T.D. Xuan, L.H. Ham, A.M. Ismail and T.D. Khanh. 2012. Molecular Breeding to Improve Salt Tolerance of Rice (*Oryza sativa* L.) in the Red River Delta of Vietnam. *International Journal of Plant Genomics*., 2012: 1-9.
- Liu, C., B. Mao, D. Yuan, C. Chu, and M. Duan. 2021. Salt tolerance in rice. Physiological responses and molecular mechanisms. *The Crop Journal*., 87(1): 1-14
- Liu, C., K. Cui, X. Zhao, X. Wang, C. Shen, Z. Yingguo, M. Dai, X. Qiu, R. Yang, D. Xing, Y. Pang and J. Xu. 2019. Identification of genes for salt tolerance and yield- related traits in rice plants grown hydroponically and under saline field conditions by genome-wide association study. *Rice.,* 12(1).
- Liu, C., Mao, B. Yuan, D.C. Chu and M. Duan. 2022. Salt tolerance in rice, Physiological responses and molecular mechanisms. *Crop Journal*., 10(1): 13-25.
- Lynch, J.P. 1995. Root Architecture and Plant Productivity. *Plant Physiology*., 109(1): 7- 13.
- Maathuis, F.J.M. 2014. Sodium in plants, Perception, signalling, and regulation of sodium fluxes. *Journal of Experimental Botany*., 65(3): 849-858.
- Mackay, I., and W. Powell. 2007. Methods for linkage disequilibrium mapping in crops.
- Marschner, P. 2011. Marschner's Mineral Nutrition of Higher Plants. *Academic Press*., 3: 111-122.
- Marschner, P. 2012. Marschner's mineral nutrition of higher plants. *Academic Press*., 3: 111-122.
- Moradi, F. and A.M. Ismail. 2007. Responses of photosynthesis, chlorophyll fluorescence and ROS-scavenging systems to salt stress during seedling and reproductive stages in rice. *Annals of Botany.,* 99(6): 1161-1173.
- Munns, R., and M. Gilliham. 2015. Salinity tolerance of crops - what is the cost? *New Phytologist.,* 208(3): 668-673.

- Munns, R., and M. Tester. 2008. Mechanisms of Salinity Tolerance. *Annual Review of Plant Biology*., 5: 651-681.
- Nazar, R., N. Iqbal, A. Masood, M.I.R. Khan, S. Syeed and N.A. Khan. 2012. Cadmium toxicity in plants and role of mineral nutrients in its alleviation. *American Journal of Plant Sciences*., 03(10): 1476-1489.
- Oladosu, Y., M.Y. Rafii, N.R. Abdullah, G. Hussin, A. Ramli, A R. Harun, G. Miah and M. Usman. 2015. Principle and application of plant mutagenesis in crop improvement, a review. *Biotechnology & Biotechnological Equipment*., 30(1):1-16.
- Parida, A.K., A.B. Das and B. Mittra. 2003. Effects of NaCl stress on the structure, pigment complex composition and photosynthetic activity of mangrove Bruguiera parviflora chloroplasts. *Photosynthetica.,* 41(2): 191-200.
- Parihar, P., S. Singh, R. Singh, V.P. Singh and S.M. Prasad. 2014. Effect of salinity stress on plants and its tolerance strategies, a review. *Environmental Science and Pollution Research*., 22(6): 4056-4075.
- Qin, H., Y. Li and R. Huang. 2020. Advances and Challenges in the Breeding of Salt- Tolerant Rice. *International Journal of Molecular Sciences*., 21(21): 83-85.
- Qin, H., Y. Li and R. uang. 2020. Advances and Challenges in the Breeding of Salt-Tolerant Rice. *International Journal of Molecular Sciences*., 21(21): 83-85.
- Raven, J.A. 1980. Short- and long-distance transport of boric acid in plants. *New Phytologist*., 84(2): 231-249.
- Rodriguez-Navarro, A., and F. Rubio. 2006. High-affinity Potassium and Sodium Transport Systems in Plants. *Journal of Experimental Botany*., 57(5): 1149-1160.
- Roy, S.J., S. Negrão. and M. Tester. 2014. Salt resistant crop plants. *Current Opinion in Biotechnology*., 26: 115-124.
- Sandhu, D., M.V. Pudussery, R. Kumar, A. Pallete, P. Markley, and WC. Bridges, and R.S. Sekhon. 2020. Characterization of natural genetic variation identifies multiple genes involved in salt tolerance in maize. *Functional & integrative genomics*., 20:261-275.
- Sen, S., and C.N. Chandrasekhar. 2014. Effect of PGPR on growth promotion of rice (*Oryza sativa* L.) under salt stress. *Asian. J. of Plant Sci. and Res.,* 4(5): 62-67.
- Shakoor, N., M. Adeel, I. Azeem, M.A. Ahmad, M. Zain, A. Abbas, and R. Yukui. 2022. Responses of Agricultural plants to Lithium pollution, Trends, Meta-Analysis, and Perspectives. *bioRxiv.,* 4(5): 62-67.
- Shi, H., M. Ishitani, C. Kim and J.K. Zhu. 2002. The Arabidopsis thaliana salt tolerance gene SOS1 encodes a putative Na^+/H^+ antiporter. *Proceedings of the National Academy of Sciences*., 99(12): 8436-8441.
- Shi, Y., L. Gao, Z. Wu, X. Zhang, M. Wang, C. Zhang, F. Zhang, Y. Zhou and Z. Li. 2017. Genome-wide association study of salt tolerance at the seed germination stage in rice. *BMC Plant Biology*., 17(1).
- *Sinauer Associates*., 6: 1-11.
- Smith, J., A. Lee and M. Thompson. 2015. Ion Uptake and Transport in Agricultural Plants.
- Sokal, R.R., and F.J. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research. *W.H. Freeman.,* 7(3): 123-136.
- Solis, C.A., M.T. Yong, R. Vinarao, K.K. Jena, P. Holford, L. Shabala, M. Zhou, S. Shabala, and Z. Chen. 2020. Back to the wild, on a quest for donors toward salinity tolerant rice. *Frontiers in Plant Science*., 11.
- Stoeva, N. and M. Kaymakanova. 2008. Effect of salt stress on the growth and photosynthesis rate of bean plants (*Phaseolus vulgaris* L.). *Journal of Central European Agriculture.,* 9(3): 385-391.
- Taiz, L., E. Zeiger, I.M. Møller and A. Murphy. 2015. Plant Physiology and Development.
- Torabi, F., A.Majd and S. Enteshari. 2015. The effect of silicon on alleviation of salt stress in borage (*Borago officinalis* L.). *Soil Science and Plant Nutrition*., 61(5): 788- 798.
- *Trends in Plant Science*., 12(2): 57-63.
- Van Zelm, E., C. Zhang and C. Testerink. 2020. Salt tolerance mechanisms of plants. *Annual Review of Plant Biology*., 71(1): 403-433.
- Very, A.A., and H. Sentenac. 2003. Molecular mechanisms and regulation of K^+ transport in higher plants. *Annual Review of Plant Biology*., 54: 575-603.
- Vibhuti., C. Shahi, K. Bargali and S.S. Bargali. 2014. Seed germination and seedling growth parameters of rice (*Oryza sativa* L.) varieties as affected by salt and water stress. *Indian J. of Agri. Sci.,* 85(1): 102–8.
- Wang, M., Y. Wang, Y. Zhang, C. Li, S. Gong, and S. Yan. 2019. Comparative transcriptome analysis of salt-sensitive and salt-tolerant maize reveals potential mechanisms to enhance salt resistance. *Genes Genom*., 41: 781-801.
- Wang, Y., W. Wu and J. Chen. 2013. Potassium Transport and Signaling in Higher Plants.
- White, P.J., and M.R. Broadley. 2001. Chloride in soils and its uptake and movement within the plant, A review. *Annals of Botany*., 88(6): 967-988.
- Wieczorek, P., B. Wrzesińska and A. Obrępalska-Stęplowska. 2013. Assessment of reference gene stability influenced by extremely divergent disease symptoms in *Solanum lycopersicum* L. *Journal of Virological Methods*., 194(1-2): 161-168.
- Zhang, H., Y. Li, and J. K. Zhu. 2018. Developing naturally stress-resistant crops for a sustainable agriculture. *Nature plants*., 4(12): 989-996.
- Zhang, X., P. Liu, C. Qing, C. Yang, Y. Shen, and

L. Ma. 2021. Comparative transcriptome analyses of maize seedling responses to salt stress. *Peer j*., 9.

- Zhao, X., W. Wang, F. Zhang, J. Deng, Z. Li and B. Fu. 2014. Comparative Metabolite Profiling of Two Rice Genotypes with Contrasting Salt Stress Tolerance at the Seedling Stage. *PLOS ONE*., 9(9): 108-020.
- Zhu, J. 2016. Abiotic stress signaling and responses in plants. *Cell*., 167(2): 313-324. Zhu, J.K. 2001. Plant salt tolerance. *Trends in Plant Science*., 6(2): 66-71.