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Physiological responses of artichoke plants to irrigation and fertilization under special recognition of salinity

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DEDICATION

To my beloved parents, who have embraced me with a tender feeling during my life,
I dedicate all my achievements.

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ABSTRACT

Artichoke productivity is strongly affected by the amount of irrigation water and fertilization mode. Likewise, salinity is one of the most severe factors limiting bud yield and its quality. Three studies were conducted: 1) to set the adequate amount of irrigation water with determining the actual crop coefficient of artichokes, 2) to identify the optimal proportion of N and K for maximum yield and quality as well as 3) to alleviate the negative effect of salinity on artichoke productivity. The effect of four irrigation rates was evaluated in northern Egypt on the local vegetatively propagated cultivar 'Balady' during the growing seasons 1998/1999 and 1999/2000. Seed-cultivar 'Green Globe' was fertigated by several proportions of N and K in summer period of 2000 and 2001 in southern Germany. In sand culture, artichoke seedlings were exposed to four NaCl concentrations in the nutrient solution, and the effect of inoculation of salt-stressed plants with *Bacillus subtilis*, supplemental Ca into saline nutrient solution and foliar application of Fe, Mn and Zn were evaluated under greenhouse conditions in 2002.

Results showed that water application according to 75-100% of pan evaporation resulted in the best plant growth and bud yield with a good product quality. Actual K_c of globe artichoke gradually increased during the growth and reached its maximum when the highest vegetation development of the crop took place, then K_c tended to decrease and remained almost constant during the generative period. Dynamic application rates of N at 300-350 kg N ha^{-1} combined with K at 400-450 kg K_2O ha^{-1} produced the best plant growth and bud yield, and even more enhanced earliness and bud quality. Salinity reduced vegetative growth and bud yield of artichoke plants, and even more lowered product quality. The productivity was ameliorated with application of *Bacillus subtilis* and nutrient additives as anti-salinity treatments. Application of *Bacillus subtilis* ranked first to alleviate the adversely effects of salinity, followed by supplemental calcium. Repeated foliar application of a mixture of Fe, Mn and Zn improved bud yield and product quality compared to the unsprayed treatments.

Keywords: Globe artichoke, Irrigation, Crop coefficient (K_c), Fertilization, N, K, Salinity, *Bacillus subtilis*, Ca, Micronutrients

KURZFASSUNG

Der Ertrag von Artischocken wird stark vom Umfang der Bewässerung und der Düngung beeinflusst. Desgleichen ist Versalzung einer der schwerwiegendsten Probleme, die Ertrag und Knospenqualität beeinträchtigen.

Drei Untersuchungen wurden durchgeführt, um für optimalen Ertrag und Knospenqualität: 1) die benötigte Wassermenge über den aktuellen K_c-Wert festzustellen, 2) die optimale Kombination der N- und K- Düngermengen zu bestimmen und 3) Möglichkeiten zur Schadensbegrenzung bei Versalzung zu testen. In den Anbauperioden 1998/1999 und 1999/2000 wurde der Einfluss von vier Bewässerungsmengen auf die vegetativ vermehrte Lokalsorte 'Balady' in Nordägypten untersucht. In 2000 und 2001 wurde in Süddeutschland die samenvermehrte Artischockensorte 'Green Globe' mit unterschiedlichen Mengen und Verhältnissen an N und K fertigiert. In 2002 wurden im Gewächshaus in Sandkultur Artischockenjungpflanzen bei vier unterschiedlichen Salzgehalten in der Nährlösung untersucht. Außerdem wurde bei etablierten Pflanzen die Wirkung von *Bacillus subtilis* im Wurzelraum, zusätzlichem Ca in der Nährlösung und die wiederholte Blattdüngung mit Fe, Mn und Zn bestimmt.

Das beste Pflanzenwachstum, Ertrag und Knospenqualität wurden mit Bewässerungsgaben entsprechend 75-100% der Pan-A Verdunstung erzielt. Der aktuelle K_c-Wert stieg während der vegetativen Entwicklung stetig an, mit Beginn der Ernte nahm der K_c-Wert leicht ab und blieb bis zu Saisonende stabil. Bei der Fertigation der Artischocken waren während der Saison abnehmende N- und zunehmende K-Gaben den konstant gehaltenen Fertigationsraten überlegen. Pflanzenwachstum, Ertrag, Frühzeitigkeit und Knospenqualität waren am besten bei Gesamtgaben von 300-350 kg N ha^{-1} und 400-450 kg K_2O ha^{-1}. Versalzung beeinträchtigte das Jungpflanzenwachstum, die gesamte vegetative Entwicklung, den Ertrag und noch viel mehr die Knospenquälität. *Bacillus subtilis* und die Nährstoffbehandlungen verringerten diese Salzwirkungen. Die stärksten Verbesserungen konnten durch *Bacillus subtilis* erzielt werden, gefolgt von zusätzlichem Ca. Die Blattdüngungen mit den Mikronährstoffen erhöhten die Knospenqualität im Vergleich zur nicht besprühten Behandlung.

Stichworte: Artischocke, Bewässerung, Crop coefficient (K_c-Wert), Fertigation, N, K, Versalzung, *Bacillus subtilis*, Ca, Mikronährstoffe

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LIST OF ABBREVIATIONS

%	percent
AAS	Atomic Absorption Spectroscopy
Agric.	Agriculture
a.s.l.	Above see level
°C	degree centigrade
CAL	Calcium-Acetate-Lactate
CLAC	The Central Laboratory of Agricultural Climate
cm	centimeter
cv.	cultivar
CU	Water consumption
DAT	Days after transplanting
Dept.	Department
DL	Double lactate
dS m^{-1}	deciSiemens per meter
DW	Dry weight
DWD	Deutscher Wetterdienst (German weather service)
EC	Electrical conductivity
e.g.	for example
E_{pan}	Pan evaporation
ET_c	Crop evapotranspiration
ET_o	Reference evapotranspiration
Exp.	Experiment
g	gram
h	hour
ha	hectar
HPLC	High performance liquid chromatography
K_c	Crop coefficient
kg	kilogram
K_p	Pan coefficient
l	liter

L	Leaching
m	meter
mg	milligram
ml	milliliter
mm	millimeter
mmol	millimole
MPa	megapascal
nm	nanometer
P	Probability
pH	soil reaction
ppm	parts per million (mg/kg)
RCBD	Randomized complete block design
RH	Relative humidity
s	second
t	ton
T	Treatment
Temp.	Temperature
µmol	micromole
WR	Water requirement
WUE	Water use efficiency

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1. INTRODUCTION

1.1 Globe artichoke in the world

Globe artichoke (*Cynara cardunculus* L. var. *scolymus* (L.) Fiori) is an important vegetable crops, which belongs to Composite family (Asteraceae). The immature flower bud is the edible part, which includes the fleshy receptacle and fleshy tender basis of bracts. Artichoke is a native Mediterranean crop (Ryder *et al.*, 1983). Nearly 85% of the world's artichoke (118723 ha in 1999) is grown in the countries bordering the Mediterranean basin. Italy is the largest producer as well as the largest consumer of artichokes (Bianco, 2000). The total world production of artichoke increased from 1.141 to 1.290 million tons from 1995 to 2000 (Behr, 2001).

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1.2 Globe artichoke in Egypt and water situation

Egypt is considered as one of the countries with the highest artichoke productivity per unit area in the world (FAO, 1999). Artichoke was cultivated on 4564 ha in 2000, which produced 87968 t of bud yield with an average of 19.3 t ha^{-1} (The year book of Agric. Statistics and Economic Agric. Dept., Ministry of Agric., Egypt). Artichoke is grown in El-Behira, Alexandria and Giza governorates and newly reclaimed lands. Nowadays, more attention is given to promote artichoke production in order to satisfy the increased demands of the local consumption as well as for exportation purposes.

Water resource in Egypt represented by Nile river water is limited (55.5 km^3 per year), according to the international law among Nile basin countries. With rapidly growing population, which is mainly concentrating around the Nile, the gap between the supply and demand for water is widening. The total agriculture land in Egypt is about 3.3 million hectares, which is almost entirely dependent on irrigation. Egypt has to save water to cultivate new areas in the desert to satisfy the high rates of population growth. Accordingly, it is advised to evaluate plant production under highest water use efficiency (WUE) using modern irrigation techniques. This may help to reduce the losses of irrigation water and increases cultivated area. Therefore, it is necessary to study the water requirements during different growth stages.

1.3 Globe artichoke in Germany

Germany is considered the largest artichoke importing country, both for fresh and processed products, with 30000 tons and 11000 tons, respectively (Bianco, 2000). Recently, globe artichoke has been proven of commercial value as a horticultural crop for Germany also. Moreover, the harvest period for artichoke in Germany in the summer months is economically interesting because in most export countries there is no production during these months. Thus, German market supplied from domestic production during those months provides good prices for this promising vegetable crop (Halter *et al.*, 2000).

1.4 Outline of the studied trials

Five-year study was conducted by fruitful cooperation between the Chair of Vegetable Science, Center of Life Sciences Weihenstephan, Technische Universtät München, Freising, Germany and National Research Centre, Dokki, Cairo, Egypt under Channel System, supported by Egyptian Government (General mission administration in Cairo and Cultural office in Berlin).

Generally, water deficit, low soil fertility and increasing salinity are major factors threatening the food production in the world. Higher yield of artichoke and quality improvement of the product have been often attributed to the appropriate supply with water and nutrients and to improve salt tolerance under arid and semi-arid conditions. Therefore, the presented studies are divided into three parts (irrigation, fertilization and salinity).

Artichoke productivity is strongly affected by the amount of irrigation water. To attain a good irrigation management, the water consumption of the crop should be known. A reference evapotranspiration (ET_o) and crop coefficient (K_c) values are frequently used to estimate crop evapotranspiration (ET_c) (Boari *et al.*, 2000). In the first trial, the local cultivar 'Balady' in Egypt was irrigated with four different levels of water (see chapter 3.1). Water requirement was calculated based on class A pan evaporation method. Volumetrically, lysimeters were used in this evaluation under new reclaimed lands in northern Egypt.

The amount and kind of fertilizers affect growth, yield and product quality of artichoke. In addition, the balance between N and K and its timing of application also influence these

agronomic traits. N increases both vegetative growth and yield, whereas K promotes early maturity and improves bud quality. In the second trial, artichoke plants (cv. Green Globe) were fertigated with several different proportions of N and K under Bavarian (Germany) field conditions (see chapter 3.2).

The third challenge for increasing artichoke yield and quality is to alleviate the adverse effects of salinity. Salt stress is known to be a limiting factor for plant growth, yield and quality of harvest product. It is a serious problem for commercial agriculture in many arid and semi-arid regions, where rainfall is normally lower than evapotranspiration. In coastal and sub-coastal areas in the Mediterranean basin (artichoke's cultivation areas) including Egypt, the salinization of irrigation water is an increasingly concerning issue. Although artichoke is placed in the moderately salt-tolerant category, especially during the vegetative stage (Francois, 1995), yield and bud quality is highly affected by salinity with negative effect. In many cases, salt-stress is caused by irrigation with saline water. While water of better quality is difficult to obtain, a series of practices can be sought to lessen the adverse effect of salinity on the plants.

The beneficial effect of supplemental Ca on growth of salt-stressed plants has been widely recognized (Lopez and Satti, 1996; Caines and Shennan, 1999; Navarro *et al.*, 2000; Bia *et al.*, 2001; Kaya *et al.*, 2002). Recently, the application of bacteria strains *Bacillus subtilis* has been shown to improve the negative effect of salinity and provide enhancement effects as biocontrol agent for several vegetable crops (Bochow *et al.*, 2001; Schmiedeknecht *et al.*, 2001). Up till now, no studies have been undertaken concerning any ameliorative factors to overcome salt problem for artichoke. There is an obvious need for research. Thus, artichoke seedlings (cv. Green Globe) were evaluated under saline conditions and the effectiveness of anti-salinity treatments such as nutrient supply and biocontrol agent were investigated under controlled greenhouse conditions in the third part of this investigation (see chapter 3.3).

1.5 Objectives of the Thesis

Increasing yield and improving quality of artichoke buds were major goals. For intensification of productivity, the seed-grown cultivar 'Green Globe' was dripper irrigated with fertilization to achieve more efficiency.

Irrigation trial aimed to evaluate artichoke growth, yield and product quality under different levels of water supply to set an adequate amount and to determine the actual crop coefficient (K_c) for different growth stages in Egypt.

The objective of the fertilization trial was to investigate the effect of different N and K application rates with varying N:K ratios on vegetative growth, yield, earliness and bud quality of globe artichoke during summer period in southern of Germany.

Salinity trials were simulated in the greenhouse under hydroponic conditions to evaluate artichoke plants under saline conditions and ameliorate the adverse effect of salinity by supplementary calcium, foliar application with mixture of micronutrients (Fe-Mn-Zn) or by inoculation with *Bacillus subtilis*.

2. REVIEW OF LITERATURE

The review of literature will deal with the different responses of the artichoke, vegetative growth, bud yield as well as quality of the product to irrigation, fertilization and salinity.
For clarity, the literature will be reviewed under the following headings:

2.1 Effect of Irrigation

Water is a major constituent of living plant tissues, which consists of approximately 90% water. It is essential for plant growth and many biochemical processes depend on it. For instance, water is a major constitute of the essential process of photosynthesis. Also, it acts as a solvent in which most plant substances are dissolved. Water is a translocating agent of organic and mineral constituents.
Water requirements are variable from one crop to another, depending on many factors, e.g., soil types and weather conditions. Plant growth, development and maximal crop yield are obtained by optimal water supply. On this basis, the response of artichoke productivity to irrigation mode will be reviewed.

2.1.1 Water requirements of artichoke

In most cases annual rainfall is not satisfactory in terms of quantity and distribution, thus supplementary irrigation is required. Artichoke is a water-demanding crop and in countries with warm and dry summers and falls, required supplementary irrigation water reaches the level of 700 to 800 mm. In these countries irrigation is initiated at planting time or about one month after cut-back in established fields. For example, in the major California production area, the annual rainfall of 300-500 mm is concentrated largely in the period from November through April (De Vos, 1992). As a result, three to five supplemental sprinkler irrigations of 80-100 mm each are applied during the growing season.
In Italy, Pellicciari and Sismondo (1976) compared the application of 200, 400 and 600 m^3 ha^{-1} after 50, 100 or 150 mm of water had evaporated from a class A pan. The treatments had little influence on cumulative yields but some treatments produced higher early yields. For example, 400 m^3 applied after 50 mm evaporation or 600 m^3 after 100 mm was most effective for early yield, and the second one was better when the irrigation water was saline.

Husain and Stewart (1996) noticed that 25 mm water per week via drip irrigation resulted in high bud yield of globe artichoke (cv. Green Globe) in Quebec, Canada.

In Italy at Gioia Tauro (RC) plane Litrico *et al.* (1998) evaluated three different irrigation volumes, corresponding to 33, 66 and 100% of maximum evapotranspiration and applied to three cultivars (Talpiot, 044 and 137F1) of globe artichoke grown from seeds. The highest yield was obtained by applying the highest irrigation volume, corresponding to 452.4 mm of water in one season. While between 66% (301.3 mm) and 33% (150.7 mm) of maximum evapotranspiration, no significant differences were observed. With regard to cultivars, cv. 044 has shown the highest yield.

Boari *et al.* (2000) worked on artichoke (cv. 044) propagated from seeds and growing in weighing lysimeters placed in a large field at Policoro (Italy) during two seasons. Total maximum evapotranspiration was 967 mm in the first season and 911 mm in the second one. Total yield for two years were 12.1 and 14.7 t ha^{-1}, respectively. Water consumption was 85% higher compared to a vegetatively propagated crop in the same area and with similar length of cropping period, likely due to higher biomass production of the seed-propagated crop. Furthermore, the water consumption was observed to decrease from 763 to 441 mm from the first to the fourth year as vegetation vigor and yield progressively dwindled in a four-year-old artichoke field on the Apulian Adriatic sea coast.

Foti *et al.* (2000) found that slight differences were detected in both ecophysiological and yield responses between two water supplies of 50 and 100% of maximum evapotranspiration. In fact, by decreasing water quantities from 100 to 50% of maximum evapotranspiration stomatal conductance, leaf transpiration, earliness and bud yield decreased by 3, 14, 14 and 6%, respectively with artichoke (Orlando F_1) in southern Italy.

Five different doses of applied water to globe artichoke (cv. Blanca de Tudela) by sprinkler were studied in Navarra region (Spain) by Macua *et al.* (2000). Results for two seasons proved similar, the different irrigation doses bearing influence on total yield but not on earliness. Total yields ranged from 20 to 6 t ha^{-1} and 19 to 11 t ha^{-1} corresponding to the greatest and the smallest irrigation doses (611 to 18.5 l m^{-2} and 630 to 29 l m^{-2}) for two successive seasons, respectively. In terms of quality, dry matter content and fiber percentages were analyzed at three periods during the harvesting time, the highest figures for both parameters coming from the smallest water doses.

With globe artichoke (cv. Violetto di Provenza), Tarantino *et al.* (2000) investigated two different watering volumes corresponding to 1.0 and 1.5 of evapotranspiration in Italy. Water was applied by micro-irrigation whenever the crop lost 30 mm of evapotranspiration. Artichoke plants irrigated with the highest watering volume showed an increase in the number of buds.

2.1.2 Methods of irrigation

Furrow irrigation is used in most artichoke plantation areas in Egypt. Recently, drip irrigation system has been introduced successfully for globe artichoke production as well as sprinkler irrigation especially under newly reclaimed lands.

Pellicciari and Sismondo (1976) found that sprinkler and furrow irrigation at three rates resulted in the same cumulative yield of artichoke buds in Italy.

De Malach *et al.* (1996) suggested to design a double-emitter source irrigation system with artichoke for brackish water conditions, using trickle instead of sprinkler irrigation. Two contiguous trickle laterals and their emitters are connected and coupled together to form a double-joint lateral. One line delivers fresh water and the other brackish water to irrigate artichoke.

Usually, irrigation is performed by sprinkling with both mobile and fixed installations in Italy. However, the use of local low-pressure irrigation (drip, intermittent sprinkling, bored hoses) is becoming widespread. Boari *et al.* (2000) reported that no significant differences were recorded in artichoke plants (cv. 044) watered with two irrigation methods (drip and sprinkler). Total yield, average bud weight and water use efficiency did not show any differences between the two irrigation methods.

Fertigation (drip irrigation with dissolved fertilizer) was compared to drip or furrow irrigation. Mansour *et al.* (2000) evaluated several modes of irrigation and fertigation with globe artichoke (cv. Violet d' Hyeres) in Tunisia. Higher yield of artichoke was obtained with the fertigation mode, with an increase of 16% and 71% compared to drip irrigation and furrow irrigation, respectively. In addition, the average bud number per plant was also higher by fertigation (8.3 buds plant^{-1}) compared to 7 buds plant^{-1} for drip irrigation against 5 buds plant^{-1} only for furrow irrigation. Moreover, water use efficiency was improved by fertigation, where it ranked first followed by drip irrigation, with furrow irrigation camping in the last.

2.1.3 Timing and intervals of irrigation

In Egypt, offshoots and stump cuttings from mother plants are planted into wet soil and subsequently irrigated at 7-10 days intervals until the offshoots are completely established. The intervals are increased during winter months (every 3 weeks) and decreased during spring months (every 2 weeks). With temperature increasing in April and May plants are irrigated weekly. Water is stopped at the end of May to prevent root rot according to Instructions lectures (1997) laid down by the Ministry of Agriculture, Egypt.

Zerbi and Ruggiero (1973) varied the irrigation start after the dry period from 5 July until 20 September with 15 days irrigation intervals after the irrigation has started. Water applied at two rates that required to bring a 25 cm soil layer to field capacity and double this rate. Yields were lowest, where watering begun in July or August owing to a heavy attack of *Sclerotium rolfsii*. Only in one of two experimental years, the higher irrigation rate resulted in a greater yield.

In Tunisia, Harbaoui *et al.* (1976) reported that giving the first irrigation late at medium of August combined with one foliar application of gibberellic acid (GA_3) at 30 ppm at the 6-leaf stage of growth, hastened maturity by more than one month when compared with early irrigation in July alone. Total yield of buds was highest when the first irrigation was given late at the first of September and the same GA_3 treatment was applied.

In addition, Harbaoui and Verlodt (1977) mentioned that general quality of bud such as bud size was improved by giving the first irrigation late on 15 August or 1 September, compared with 15 July or 1 August and applying 30 ppm GA_3 at the 6-leaf or 8-leaf stage and again 3 weeks later.

The opposite trend was found in Izmir, Turkey. Early irrigation was found to be more practical than GA_3 treatment (Eser *et al.*, 1985). In their studies with artichoke (cv. Sakiz), irrigation was started in the first week of August, the third week of August, or the first week of September, and 30 ppm GA_3 was applied once when the plants had 6-8 leaves, or at this stage and again 3 weeks later. Early yield was improved by early irrigation and by double GA_3 application but total yield and bud size were unaffected.

2.1.4 Effect of propagation method

The physiological responses of artichoke to irrigation management vary with propagation method. Therefore, water requirement of plants is not the same if vegetatively- and seed-

propagated. Cosentino and Mauromicale (1990) investigated two water regimes of 50% and 100% of evapotranspiration and two genotypes with different propagation methods ('Violetto di Sicilia' vegetatively propagated and 'Talpiot' seed-propagated). On average of all measurements carried out during the irrigation season, leaf transpiration and stomatal conductance resulted significantly different due to both studied factors. However, the differences between the genotypes were much higher than those between the water regime treatments. The values of transpiration and stomatal conductance of 'Talpiot' were irrespective of water regime 46.1% and 49.2%, respectively, higher than those of 'Violetto di Sicilia'. Leaf water potential resulted significantly different between genotypes, while it did not show any significant difference between the two water regimes. The values of leaf water potential of 'Talpiot' (-6.9 bars) were significantly higher than that of 'Violetto di Sicilia' (-12.2 bars). The immediate formation and the rapid growth of the root in the seed-propagated compared to the vegetatively propagated plants could account for the behaviour of the two varieties.

Boari *et al.* (2000) mentioned that water consumption of artichoke plants propagated from seeds was 85% higher than in a vegetatively propagated crop in the same area and with similar length of cropping period. Likely this was due to higher biomass production of the seed-propagated plants.

2.1.5 Crop coefficient (K_c)

Generally, crop coefficient (K_c) values are gradually increased during plant growth but decrease at the end of season. Measured changes of K_c values by Prados (1989) for several fruity vegetable crops (tomatoes, peppers, cucumbers, beans, trained melons and water melons) followed the same rules with initial values of 0.2-0.3 increasing to 1.0-1.2 and then reducing to 0.8-0.9 at the end of the growth cycle of the crop. For artichoke, Boari *et al.* (2000) calculated crop coefficient (K_c) values using weighing lysimeters placed in a large field. The crop coefficients (K_c) were calculated for 10 days-intervals. The mean K_c increased from about 0.5 at the beginning of crop cycle (seedling time), to about 1.4 at the end of October (vegetation development). K_c remained almost constant with slight variations around 1.5 during wintertime until the end of March when the highest vegetation development of the crop took place. Later, this value progressively increased attaining 1.7

at the end of April corresponding to the beginning of harvests. During harvest it then diminished to 1.5 at the end of the crop cycle.

2.2 Effect of Fertilization

A wide range of soil types can be used profitably for commercial production of artichoke. However, optimum productivity has been obtained on deep, fertile, well-drained soils of sandy loam to clay loam textures. Soil fertility may be defined as the capacity to supply plant nutrients in adequate amount and in suitable proportion. The fertility develops by application of organic manure and mineral fertilizers. Moreover, the nutritional requirement of plants could not be fully met by the use of organic manure only. Hence, mineral nutrient application becomes essential to satisfy nutrient uptake. It is universally accepted that the use of mineral fertilizers is an integral part of the package of practices for raising the agricultural production.

2.2.1 Role of nitrogen and potassium

Among the major nutrients nitrogen and potassium play an essential role for plant production. Nitrogen and potassium are the most important elements in plant nutrition.

Nitrogen is a primary plant nutrient to achieve maximum crop yield. Plants absorb nitrogen in the greatest amount of any essential nutrients. Depending on the plant species, development stage and organ, the nitrogen content required for optimal growth varies between 2 and 5% of the plant dry weight (Marschner, 1995). Nitrogen is an essential constituent of metabolically active compounds such as proteins, enzymes, nucleic acids and chlorophyll. N plays a major role in cell division and improves photosynthesis process, which results in higher accumulation of organic matter in plant tissues. When nitrogen is a limiting factor, the rate and extent of protein synthesis are depressed and as a result plant growth is affected. Moreover, plant gets stunted and develops chlorosis. Inadequate nitrogen supply often is the growth-limiting nutritional stress in the field. Consequently, addition of N usually improves plant growth and yield.

Next to nitrogen, potassium is the mineral nutrient required in the largest amount by plants. It is the most prominent inorganic plant solute and is the only mineral nutrient that is no constituent of organic structures. Its function is mainly in osmoregulation, the maintenance

of electrochemical equilibria in cells and its compartments and the regulation of enzyme activities (Hsiao and Läuchli, 1986). Potassium has a crucial role in the energy status of the plant, translocation and storage of assimilates and maintenance of tissue water relation (Marschner, 1995). K plays a key role in production of crop quality. It improves size of fruit and stimulates root growth. It is necessary for the translocation of sugars and formation of carbohydrates. K also provides resistance against pest and diseases and drought as well as frost stresses (Imas and Bansal, 1999).

2.2.2 Application of fertilizer

Ideally, fertilization must supply and maintain an optimum level of nutrients within the root zone (Papadopoulos, 1985). Nutrients are supplied to growing plants by several methods, such as application to the soil, through irrigation water and by foliar applications. Important nutrients such as N and K can easily be applied through drip irrigation systems by fertigation (Papadopoulos, 1996).

Fertilizer schedules should be timed for the entire cultivation cycle of a crop. The rates of N and K and application time as well as intervals are of vital importance for adequate uptake and optimal growth. These nutrients must be applied in correct proportions.

According to the recommendations of the Ministry of Agriculture of Egypt, 50-70 m^3 farmyard manure and 90 kg P_2O_5 ha^{-1} (Calcium Superphosphate 15.5% P_2O_5) should be soil-incorporated before artichoke planting. Nitrogen (Ammonium Sulphate 20.5% N) is side dressed at 244 kg N ha^{-1} in 5 equal doses during artichoke growing season. The first one is applied after the complete offshoots establishment. The second and third are applied before and while bud formation before harvest. The fourth and fifth are applied during harvesting season. Potassium (Potassium Sulphate 49% K_2O) at 60 kg K_2O ha^{-1} is applied when plants enter the generative stage. Foliar application of 120 mg l^{-1} of Fe, 384 mg l^{-1} of Mn and 224 mg l^{-1} of Zn at 60, 80 and 100 days after planting encourage the earliness of bud production.

Caruso (1966) reported that gypsum application enhanced the response of globe artichoke to NPK on calcareous clay soils but not on soils low in active Ca when irrigated with saline or non-saline water.

Recommended application rates for artichoke in southern France are 100 kg P_2O_5, 400-500 kg K_2O and 120-140 kg N ha^{-1} in autumn, with 1 or 2 further split applications of N in spring (Moulinier, 1980).

De Vos (1992) mentioned that in each production cycle, Californian growers typically apply fertilizers in the range of 168 to 336 kg ha^{-1} of N, 56 to 112 kg ha^{-1} of P_2O_5 and 34-112 kg ha^{-1} of K_2O. All of the P and K and much of the N are supplied in the first fertilizer application when the new-planted crop has established or the regrowth from cut-back plants has started. In established fields, this initial fertilization usually consists of either a side dress application of dry material, or a liquid fertilizer injection into furrows. Additional N is supplied in two or three applications. Following cut-back and preparing for the next crop cycle, it is common for growers to apply up to 22.4 tons ha^{-1} of organic manure, primarily as a source of organic matter and production improvement.

2.2.3 Vegetative growth

Artichoke plants are known to produce a huge vegetative biomass during a long growing season. Therefore, fertilization is ought to play an important role in artichoke productivity. Production of artichoke seedlings with high quality is required. In a study aimed for this reason, Elia and Santamaria (1994) determined the suitable levels of NPK fertilizers. Nutrient solution should contain at least 130 mg N l^{-1} and rates of 100 and 250 mg l^{-1} of P and K, respectively. These rates produced the best plant height, leaf area and number, shoot fresh and dry weight as well as root dry weight with improvement of the root:shoot ratio.

In another study, Elia *et al.* (1996) investigated 4 different ratios, 100:0, 70:30, 30:70 and 0:100 of ammonium to nitrate (NH_4:NO_3) to determine the best ratio of nitrogen forms in nutrient solution for artichoke growth. Obtained results indicated that NO_3 is the N-form preferred by artichoke. Nutrient solution containing 70-100% NO_3 resulted in the best vegetative growth with highest leaf area, root volume and dry weight. Increasing NO_3-N increased water use efficiency, whereas, 243 ml of water were enough to produce 1 g of dry matter when a solution contained 75-100% NO_3, but 623 ml were required to produce the same unit of dry matter with solutions of 100% NH_4.

Gerakis and Honma (1969) reported that the fresh plant weight of globe artichoke growing in organic soil in Michigan (USA) were markedly influenced by N fertilizer up to 200 kg N ha^{-1}. While, P and K levels had no significant effect.

El-Abagy (1993) investigated three NPK levels, low level (71 kg N, 57 kg P_2O_5 and 119 kg K_2O ha^{-1}), medium level (142 kg N, 114 kg P_2O_5 and 238 kg K_2O ha^{-1}) and high level (213 kg N, 171 kg P_2O_5 and 357 kg K_2O ha^{-1}) with globe artichoke cultivated in a clay soil in Egypt. The author recommended to supply the medium level with the highest plant height, number of leaves per plant and leaf fresh weight as well as leaf dry weight.

Pedreno *et al.* (1996) reported that the reduction of nitrogen application from 500 to 300 kg N ha^{-1} resulted in reduction of total biomass of artichoke.

During two successive seasons, Salamah (1997) investigated the response of artichoke (cv. Herious) to N-fertilization levels ranging from 95 to 380 kg ha^{-1} in Ismailia region, Egypt. The obtained results indicated that all characteristics of plant growth such as number of leaves as well as leaf fresh and dry weight were markedly increased when N-fertilization increased from 95 to 285 kg N ha^{-1} without further increases when N-level increased from 285 to 380 kg N ha^{-1}.

Slight differences were detected in ecophysiological measurements of artichoke response among different levels of nitrogen fertilization. Foti *et al.* (2000) noticed that the response of leaf transpiration and stomatal conductance to nitrogen rates was not linear. The physiological measurements were high with 200 kg N ha^{-1} compared to non-application (control). While, there was no effect of N fertilization between 200 and 400 kg N ha^{-1}.

2.2.4 Yield and quality

The influence of fertilization to achieve a high yield and generally good quality of vegetable crops is well known. Good artichoke yield is the result of integrated effects of many factors that influence plant growth during different growth stages. Balanced fertilization is one of the most important factors affecting artichoke productivity. Concerning the effect of NPK fertilization on yield and quality of artichoke, the experimental results obtained in different producing areas present many discrepancies, depending on the soil fertility and fertilizer application rates. For instance, Baroccio (1969) compared three dosages of N (60, 120 and 180 kg N ha^{-1}), P (0, 100 and 200 kg P_2O_5 ha^{-1}) and K (0, 100 and 200 kg K_2O ha^{-1}) in Rome region. Results indicated that the highest and most economic return was obtained

with medium N (120 kg ha^{-1}), high P (200 kg ha^{-1}) and no K. The next best treatment was high N (180 kg ha^{-1}), high K (200 kg ha^{-1}) and no P. Very good results were also obtained with all 3 nutrients at medium level or at high level. In general, the author concluded that N application increased yield, whereas, P fertilization improved quality characteristics of the buds (except in the absence of K) and K promoted early maturity as well as improved quality.

Gerakis and Honma (1969) denoted that the application of nitrogen to an organic soil described as 'Houghton muck' improved artichoke productivity. In a field trial in Michigan (USA), earliness of bud was markedly influenced by N fertilizer up to 200 kg N ha^{-1}. On the other hand, P and K application had no significant influence. The weight of the main and lateral buds was not affected by adding N, P or K fertilizers.

Prado *et al.* (1983) indicated that increasing nitrogen application from 0 to 320 kg N ha^{-1} as urea increased the number of marketable buds from 10122 to 21276 ha^{-1}.

In a silty-clay soil (rich in nitrogen) in southern Italy, Elia *et al.* (1991) evaluated artichoke productivity with N application rates of 150 and 300 kg N ha^{-1} compared to the control of non-application. They noticed that the application of 150 kg N ha^{-1} was sufficient to increase the yield by 3 t ha^{-1} by both higher number and weight of buds per plant without further increase over 300 kg N ha^{-1}.

Medium NPK fertilizer levels (142 kg N, 114 kg P_2O_5 and 238 kg K_2O ha^{-1}) ranked the first among 3 investigated combinations of NPK levels concerning production of both early and total yield (El-Abagy, 1993). Moreover, medium level of NPK proved to be quite sufficient under clay soil conditions in Egypt for producing the highest quality of bud parameters such as weight of bud and edible part.

Pomares *et al.* (1993) studied the effect of NPK fertilization at three doses on artichoke (cv. Blanca de Espana) productivity in Valencia, Spain. There was no significant response on the yield with N dosage higher than 200 kg ha^{-1}, where only slight differences were obtained with 400 or 600 kg N ha^{-1}. Moreover, PK fertilizers did not increase bud yield. The obtained results showed that levels of available P from 27-33 ppm and of available K from 250-282 ppm in the soil were adequate for the optimal growth of artichoke.

Pedreno *et al.* (1996) detected that bud yield was not affected by increasing N application to calcareous soil from 300 to 500 kg N ha^{-1}.

Salamah (1997) reported that application of 285 kg N ha^{-1} promoted earliness and significantly increased the portion of early yield from total yield. In contrast, increasing N fertilization to 380 kg N ha^{-1} markedly delayed bud appearance on plants and significantly decreased the portion of early yield. Bud traits such as length and weight as well as receptacle diameter were best with a N fertilization rate higher than 95 kg N ha^{-1}. Increasing N levels had no effect on bud diameter and thickness of receptacle.

Foti *et al.* (2000) demonstrated that 200 kg N ha^{-1} as NH_4NO_3 is sufficient in southern Italy for economic yield of artichoke (Orlando F_1). The yield response to nitrogen rates was not linear. Bud yield with 0 kg N ha^{-1} was the lowest, followed by those fertilized crops with either 200 or 400 kg N ha^{-1}. Earliness and total yield were better by 200 kg ha^{-1} of N.

2.2.5 Plant chemical composition

There is a close relationship between fertilizer application and plant chemical composition. The concentration of several nutrients in globe artichoke leaves was influenced by 15 various nutritional environments and sampling techniques in pot experiment under greenhouse condition (Gerakis and Honma, 1969). Nutrient solution lacking N, P, K, Ca, Mg, Mn or Fe differed from the control (Hoagland solution) for that nutrient. High levels of P and Mn in the solution caused marked increases in the leaf concentration of these nutrients. Nutrient deficiency symptoms developed for N, P, K, Ca, Mg and Fe and were most characteristic for N and Ca. On the opposite, no deficiency symptoms were developed for Mn.

Gabal *et al.* (1988) reported that spraying some foliar fertilizers (Irral, Bayfolan or Folifertile), which include NPK and other micronutrients led to an increase in chlorophyll and carotene content of artichoke leaves. This increase ranged from 18-40% and 12-55% for chlorophyll and carotene content, respectively, and depended on level and kind of used fertilizers. Sugar content of leaves did not respond to any foliar fertilizer application.

El-Abagy (1993) compared the application of 71 kg N, 57 kg P_2O_5 and 119 kg K_2O ha^{-1} to the double and threefold rate for artichoke on a clay soil in Egypt. N, P and K contents of plant leaves were not affected by the levels of fertilization. Medium level of fertilization showed superiority in chlorophyll, carotene, total sugars and phenols content in leaves and total sugars content in the edible part. With increasing NPK levels leaf inulin content tended to increase but inulin as well as fiber content of the edible part gradually decreased.

N and NO_3-N content in artichoke leaves tended to increase when N fertilizer dosage was increased from 200 to 600 kg ha^{-1}. The content of P and K was not influenced by N application rates. P added to soil resulted in higher levels of this nutrient only and did not affect the other elements. K applied to soil led to higher K concentrations in the leaf but did not influence the content of N, NO_3-N and P. Generally, concentration of N, P and K in the leaves showed a marked decrease along the growing season with the age of plants (Pomares *et al.,* 1993).

Nitrogen content tended to decrease in artichoke aerial part by decreasing N application from 500 to 300 kg N ha^{-1}, with no effect on nitrogen content in the edible part (Pedreno *et al.,* 1996).

Salamah (1997) reported that artichoke leaf content of N, P and K as well as edible part content of N and K increased gradually with increasing application level of nitrogen from 95 to 380 kg N ha^{-1}.

Eich *et al.* (2000) investigated several levels of N ranging from 40 to 240 kg N ha^{-1}, half applied at time of sowing and the rest 6 weeks later. The nitrate concentration measured in the whole biomass correlated with the nitrogen amount applied, but the content of both caffeoylquinic acids and flavonoids was reduced with increased nitrogen fertilizer rates.

2.2.6 Nutrient uptake

High production of dry matter of artichoke results in large amounts of nutrients removed per unit time, which most of the soils are not able to inherently supply. Different researchers have estimated the nutrient uptake of globe artichoke. Magnifico and Lattanzio (1976) reported a nutrient removal by artichoke from fertilized soil in a single cropping cycle in southern Italy with 286 kg N, 44 kg P_2O_5 and 368 kg K_2O ha^{-1}. During the harvest period 109.2 t ha^{-1} fresh weight of total biomass were removed equivalent to 13.1 t ha^{-1} of dry matter, with an average of 15.4 buds per plant. For the production of 1 t of buds yield, fertilizer requirements were 19 kg N, 3 kg P_2O_5 and 24 kg K_2O.

Moulinier (1980) found that uptake curves for N, P_2O_5, K_2O, Ca and Mg were similar to the plant growth curve, showing particularly rapid increases from mid-March to mid-April when offshoots were developing. In southern France, with plant densities of 25000 plants ha^{-1}, the nutrient uptake was 275, 90 and 450 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. This result indicated that the fertilizer application of 150 kg K_2O ha^{-1} would in the long run

be deficient to satisfy plant requirements. Therefore, the author recommended application rates of 400-500 kg K_2O ha^{-1}.

The uptake of N and inorganic anions and cations were measured by Elia *et al.* (1996) under controlled conditions in a nutrient solution experiment. NO_3 is the N-form preferred by artichoke, and leaf is the most important site of NO_3 assimilation. Increasing NO_3-N from 0 to 100% of the total N supplied in the nutrient solution, the equivalents of mineral cations in the shoots increased by 30% and equivalent of organic anions increased by 2.3 times. By increasing NH_4 percentage in the nutrient solution, the tissue content of mineral anions was generally increased, except for NO_3.

Pedreno *et al.* (1996) found that nitrogen losses was lower under reduced mineral N application of N < 300 kg ha^{-1} compared to the traditional input of nitrogen (N = 500 kg ha^{-1}) on a calcareous soil in eastern Spain.

2.3 Effect of Salinity

Salinity is recognized as a limiting factor, influencing crop production in many arid and semi-arid areas. Numerous authors investigated the effect of salt-stress on artichoke production. The most pronounced response of globe artichoke to salinity is reduced vegetative growth and bud yield, and even more depressed product quality. Salinity adversely affects plant growth in three major ways: water deficit, ion toxicity and nutrient imbalance. All three will inhibit growth and are interrelated. For instance, toxicity of one element can result in nutrient imbalances of other elements (Alsup, 1998).

There are special strategies to decrease the negative effects of salinity on plant physiology and on agronomical traits. In this respect, some studies on vegetative crops exhibit ways to ameliorate the adverse effect of salinity by additional nutrient and bacteria applications. However, no data is available on such strategies for artichoke. Therefore, the review of literature will deal with the effect of salt-stress on artichoke productivity and take into consideration strategies mentioned above for other vegetables.

2.3.1 Germination

Soils are saline if they contain high levels of soluble salts to harm plants. Most plants are more sensitive to salinity during germination than at any other growth stage. This sensitivity is usually caused by an exceptionally high salt concentration near the soil surface, left behind as the upward moving water is evaporated (Abrol *et al.*, 1988). Salinity and water stress are connected. Salt inhibition of germination is due to osmotic effects, which reduce the hydration level of the seed, causing death if the salt-stress occurs after the critical level of hydration has been reached (Thompson, 1986).

Mauromicale and Licandro (2002) performed two experiments on seeds germination of artichoke. With the first, conducted in the laboratory, the influence of 4 levels of salinity in the germination medium and 2 germination temperatures on seeds of the cultivars 'Romanesco' and '4055' F-1 on germination response was evaluated. With the second experiment, carried out in pots in the open, the effect of 3 levels of irrigation water salinity on emergence and seedling growth was studied. Germination percentage and rate (velocity) decreased with decreasing osmotic potential of germination medium but with lower magnitude at 20°C than at 30°C. The threshold of osmotic potential that reduced germination by 50% was -1.61 MPa for 'Romanesco' and -1.75 MPa for '4055' F 1 at a germination temperature of 20°C, and significantly increased to -0.84 MPa and -1.00 MPa, respectively, at 30°C. Seedling emergence, which was 96% with tap water, declined to 48% as the osmotic potential of irrigation water decreased to -0.5 MPa and was 0 at -1.0 MPa. More than 50% of the emerged seedlings irrigated with water at osmotic potential of -0.5 MPa died 4-5 days after emergence.

2.3.2 Growth and development

Seedlings are more sensitive to high salt levels than are established plants, while established plants are more resistant to high salt levels (Nelson, 1991).

Graifenberg *et al.* (1993) aimed to determine the salt tolerance threshold (the EC that is expected to cause the initial significant reduction in the maximum expected growth) and slope (the percentage of growth expected to be reduced for each unit of added salinity above the threshold value) for artichoke growth expressed in terms of electrical conductivity of irrigation water (EC_i) and saturated-soil extract (EC_e). Cultivar 'Terom', vegetatively propagated was grown for two years in soil-filled pots in the greenhouse under

saline-sodic conditions. Plants were irrigated with 11 levels of electrical conductivity (EC_i) between 0.74 and 15.08 dS m^{-1}. The thresholds for plant fresh weight were 2.7 and 4.8 dS m^{-1} for EC_i and EC_e, respectively. At EC higher than the threshold value, the slopes for plant fresh weight were 10.9% and 8.1% per dS m^{-1} for EC_i and EC_e. Roots seemed to be less affected by salinity than shoots. In the control and up to 15.08 dS m^{-1} EC_i, shoot:root ratio changed from 3.9 to 1.2. Plants survived and produced suckers up to EC_e of 21.8 dS m^{-1}.

Under the same previous experimental condition, Graifenberg *et al.* (1995) observed a significant reduction of whole plant dry weight from 1311 to 142 g with increase of salinity from 0.74 to 15.08 dS m^{-1}. With increase in salinity, upper leaves show the greatest dry weight reduction, with a slope of 8.06% per dS m^{-1}. Root dry weight was less affected by salinity, with a slope of 5.73% per dS m^{-1}.

Francois (1995) reported that artichoke vegetative growth was more tolerant to salt-stress than was bud production. A control and five saline treatments were imposed by irrigation with waters that contained equal weights of NaCl and $CaCl_2$. Each unit increase in EC above 7.8 dS m^{-1} in the irrigation water reduced vegetative growth by 8.3%. These results place artichoke in the moderately salt-tolerant category during vegetative growth.

Vincenzo *et al.* (2000) evaluated globe artichoke (cv. Orlando) grown in the open in large pots watered with different salinity levels (EC = 0.5, 2.5, 6.5, 10.5 and 14.5 dS m^{-1}) during a period of two years. Results indicated that during the first year of the experiment, the number and basal diameter of offshoots did not change with increasing EC, during the second year both parameters declined. Offshoots emergence was delayed as the EC increased, mainly during the second year. Total biomass of leaves, offshoots and stems decreased as salinity level increased, while the underground biomass at the end of the first year was not affected. Additionally, Vincenzo *et al.* (2000) reported that net photosynthesis and transpiration rates were reduced progressively as EC increased. At the lower salinity level the values were 21 µmol m^{-2} s^{-1} and 4.5 mol m^{-2} s^{-1}, while at the highest level the values were 11 µmol m^{-2} s^{-1} and 2.3 mol m^{-2} s^{-1}, respectively.

2.3.3 Yield and product quality

Yield and product quality are much more sensitive to saline-sodic conditions than vegetative growth. For instance, Francois *et al.* (1991) observed that the number of

marketable buds was reduced by 20% or more when irrigation water salinity exceeded 2.0 dS m^{-1}, and up to 50% at 10.0 dS m^{-1}.

The same trend was reported by Graifenberg *et al.* (1993) who determined the salt tolerance threshold and slope for artichoke yield expressed under saline-sodic conditions. When irrigation EC is higher than 2.7 dS m^{-1}, the slope for bud yield was 14.4%. Also, there was 10.7% reduction in total yield per 1 dS m^{-1} when higher than 4.8 dS m^{-1} in saturated-soil extract.

In a two-year study in southern California bud yield was unaffected up to a soil salinity of 6.1 dS m^{-1} (electrical conductivity of the saturated soil extract) (Francois, 1995). Each unit increase in salinity above 6.1 dS m^{-1} reduced yield by 11.5%. The higher salinity treatments showed a tendency to produce fewer harvestable buds per plant with lower average bud circumference and even more reduced bud weight. Yield reduction was attributed primarily to reduced bud weight rather than bud number.

Graifenberg *et al.* (1995) reported that comparing all plant parts, buds showed the greatest decrease of dry weight with increase of salinity, with a slope of 8.91% per dS m^{-1}.

De Malach *et al.* (1996) found that total yield was reduced to approximately 40-50% of its maximum as irrigation water salinity increased from 1.5 to 6.2 dS m^{-1} in globe artichoke (cv. Violets de Provence).

Tarantino *et al.* (2000) reported that increasing irrigation volume was preferred for artichoke due to the leaching action when EC of irrigation water ranged from 3 to 3.5 dS m^{-1}. With increasing water levels number of buds per plant was improved.

The same cause for yield loss was reported by Vincenzo *et al.* (2000) in a pot experiment. Moreover, bud quality was adversely affected. The mean bud size was reduced, while bud dry matter and fiber content increased. When EC of irrigation water raised to the highest levels of salinity (14.5 dS m^{-1}), buds showed divaricated bracts that loose more water by transpiration and consequently become more hard and fibrous. Also, some inner bracts exhibit apical necrosis and brown discoloration along the midmargin of these bracts (Vincenzo *et al.*, 2000).

2.3.4 Nutrient distribution in the plant

The relation between salinity and mineral nutrition of horticultural crops are extremely complex. Crop performance may be adversely affected by salinity-induced nutritional

disorders. These disorders may result from the effect of salinity on nutrient availability, competitive uptake, transport or partitioning within the plant (Grattan and Grieve, 1994). For example, salinity reduces phosphate uptake and accumulation in crops by reducing availability or by competitive interactions. Salinity dominated by Na salts not only reduces Ca availability but also reduces Ca transport and mobility within the plant. Salinity can directly affect nutrient uptake, such as Na reducing K uptake or Cl reducing NO_3 uptake (Grattan and Grieve, 1999).

Francois *et al.* (1991) reported that increased incidence and severity of Ca deficiency in the inner bracts of artichoke buds were directly related to increased levels of salinity. The disorder was characterized by visible damage and necrosis of the inner bracts. Root pressure, the process that would normally improve Ca movement to the inner bracts, was severely reduced as soil salinity increased. In addition, chloride concentration in midrib and blade tissue of artichoke leaves increased as salinity increased (Francois, 1995).

Graifenberg *et al.* (1995) determined allocation of Na, Cl, K and Ca in different artichoke parts such as bud, root, stem and lower, middle and upper leaves. Leaf tissue was the most important site of ion accumulation with significant differences among the leaf positions. The highest accumulation of 36 g Na and 40 g Cl was found in the lower leaves at 5.14 dS m^{-1}, and then Na and Cl content started to decline although EC increased. In contrast, the root tissues showed a continuous increase in Na content with increasing EC of the irrigation water. Reduction in Ca and K allocation was shown in all plant tissues as EC increased, and was particularly evident in lower and middle leaves, but without visible damage in buds. Differences in bud responses of artichoke reported by the two research teams were undoubtedly the result of disparate environmental conditions. In contrast to the greenhouse pot experiments described by Graifenberg *et al.* (1995), the field trials described by Francois *et al.* (1991) and Francois (1995) were conducted in a desert area under conditions of low humidity, desiccating winds and high temperatures which increased transpiration and undoubtedly reduced root pressure. As a result, calcium distribution to shoot organs may have been strongly affected, and calcium requirement of the inner bracts was not met.

In addition, Morzadec *et al.* (1998) found that calcium deficiency in the receptacle and low water content in the leaves were associated with the incidence of black spot disorder.

2.3.5 Improvement strategies

2.3.5.1 Nutrient supplement

Salt tolerance is a plant's capacity to endure the effects of excess salt in the root zone without a significant adverse effect. Salt tolerance ratings are based on yield reduction on salt-affected soils when compared with yield on similar non-saline soils (Abrol *et al.,* 1988). Several authors have linked salinity-stress with macronutrient deficiencies. For example, high salinity has been shown to induce calcium deficiency in tomato grown under hydroponic culture (Caines and Shennan, 1999; Navarro *et al.,* 2000). Sodium ions may compete with calcium ions for membrane-binding sites. Therefore, it has been hypothesized that additional calcium may protect the cell membrane from the adverse effects of salinity (Busch, 1995; Cramer *et al.,* 1985; Cramer, 2002).

An alternative strategy for coping with salinity could, therefore, is to attempt to supplement Ca where the growth medium is known to be or may become saline. For instance, application of gypsum is a common practice in reclamation of saline-sodic and sodic soils (Marschner, 1995). The level of Ca in the external solution needed for maximal growth in saline conditions is usually between 5 and 10 mmol l^{-1} depending on the salinity level (Cramer, 2002). Likewise, the optimal Na:Ca ratio is somewhere between 10 and 20 for most plants.

The beneficial effect of calcium on tomato plants exposed to NaCl salinity was observed. Addition of calcium either alone (Caines and Shennan, 1999; Navarro *et al.,* 2000) or in combination with potassium (Lopez and Satti, 1996) to saline nutrient solution increased root volume, fresh weight, fruit yield and concentrations of both Ca and K in plant leaves. The additional Ca as $CaSO_4$ form was preferable than $CaCl_2$ form for saline-stressed tomato (Caines and Shennan, 1999). Bia *et al.* (2001) studied the effect of Ca on lettuce plants exposed to Na_2SO_4 salinity. Supplemental Ca improved shoot growth, photosynthetic rate and gas exchange as well as increased the content of Ca and diminished the content of Na in the shoots.

Likewise, calcium supplemented into nutrient solution alleviated the negative effects of salinity on strawberry plants for both plant growth and fruit yield (Kaya *et al.,* 2002). Where, water use by plant increased and Ca deficiency in the leaves was corrected by additional Ca. Moreover, membrane permeability increased with elevated NaCl and this increase in membrane permeability was decreased with supplementary Ca.

2.3.5.2 Biocontrol agent

It is well known that a considerable number of bacterial species, mostly those associated with the plant rhizosphere are able to exert a beneficial effect on plant growth. The use of those bacteria as biofertilizers or biocontrol agents in agriculture has been a focus of research for a number of years. The bacteria strains isolated and commercialized by FZB Biotechnik GmbH Berlin (Germany) were tested for their in vitro performances (Krebs *et al.*, 1998; Schmiedeknecht *et al.*, 2001) and in vivo performances on potato (Schmiedeknecht *et al.*, 1998) and on tomato (Böhme, 1999; Grosch *et al.*, 1999). All the monitored activities and formulation properties suggest an effective use of *Bacillus subtilis* as a plant-strengthening agent and for biocontrol of diseases.

The rhizobacterium *Bacillus subtilis* strain FZB24 WG, a new bioproduct registered as biocontrol agent was tested as a promoter for salt tolerance. The degree of tolerance that can be induced by *Bacillus subtilis* is varying among plant species. Bochow *et al.* (2001) reported that *Bacillus subtilis* caused 50 and 25% reduction in salinity effect on the yield of eggplant and pepper, respectively. Compared with the unsaline-irrigated control, the yield was progressively reduced up to 92% in eggplant, and up to 94% in pepper, due to irrigating the plants with saline water (6.6 dS m^{-1}). By using saline water and bacterization, the yield increased up to 550% in eggplants, and up to 430% in pepper, with significant promotions in the other plant growth parameters compared to irrigation of saline water only.

3. MATERIALS AND METHODS

3.1 Irrigation experiment

3.1.1 Experimental site

A lysimeter study was conducted in two cropping periods from 1998 to 2000 at El-Bossily Site of Protected Cultivation (31° 40' N, 30° 40' E, at an altitude of 3 m a.s.l.), El-Behira Governorate, northern Egypt.

Location weather data for monthly average temperatures (Temp.), relative humidity (RH), total rate of rainfall and sunshine hours are presented in Table 3.1.

Table 3.1 Average values of main weather parameters in El-Bossily Site (historical data for 10 years)

Month	Temp. (°C) Mean	Rainfall (mm) Total	Sunshine (h) Total	RH (%) Mean
January	13.0	56.3	179.8	69.0
February	13.8	28.9	198.8	71.0
March	15.5	11.7	244.9	65.0
April	18.0	5.8	258.0	66.5
May	20.6	2.5	322.4	65.0
June	24.3	0.0	366.0	66.0
July	25.7	0.0	372.0	70.0
August	26.3	0.2	347.2	71.0
September	24.5	0.6	300.0	70.0
October	22.5	10.7	266.6	72.0
November	18.9	26.6	204.0	72.0
December	15.2	50.0	186.0	70.0
Total/Mean	19.9	190.8	3245.7	69.0

Source: The Centeral Laboratory for Agricultural Climate (CLAC), El-Bossily Station, Rosetta, Egypt

The soil texture is sandy with 95.3% sand, 0.4% silt and 4.3% clay. Chemical properties of the experimental soil are given in Table 3.2.

Table 3.2 Chemical properties of the experimental soil at El-Bossily Site

pH	EC [dS m^{-1}]	Anions [mg $100g^{-1}$]		Cations [mg $100g^{-1}$]			
		HCO_3	Cl	Ca	Mg	Na	K
7.92	3.0	18.0	47.8	23.6	13.9	29.2	21.4

3.1.2 Materials

The experiment was carried out in a randomized complete block design (RCBD) with three replicates. The plot area was 22.5 m^2 containing 15 artichoke plants and one lysimeter (see chapter 3.1.3). Drip irrigation system with good quality water was used daily. Before planting, 90 kg P_2O_5 ha^{-1} was soil-incorporated and 244 kg N ha^{-1} and 60 kg K_2O ha^{-1} were applied (Broadcast) during the plant growth stages. Other agricultural practices such as weed control and pest management were followed according to Instructions lectures (1997) by the Ministry of Agriculture, Egypt.

The local cultivar ‘Balady’, vegetatively propagated, was used in this investigation during the two successive seasons of 1998/1999 and 1999/2000. Planting was on September third and ninth in the first and the second season, respectively, with 100 cm apart between each two plants on the ridge and 150 cm between the ridges, resulting in a planting density of approximately 7000 plants per ha. The first harvest of buds started in January and continued until the end of May in both seasons.

3.1.3 Experimental plan

The lysimeter study investigated four irrigation treatments for the optimal water regime during plant growth.

A metal lysimeter tank with 1.0 m x 1.0 m surface area and 0.5 m depth was used. It contained a hole at the lateral bottom connected with a corroborated drainage tube and a collector for the drained water. The bottom of the lysimeter was filled with 2 cm layer of gravel to improve the drainage. The rest of the lysimeter was filled with the local soil up

to the natural level of the soil surface. The entire experimental field was well watered by furrow irrigation, before planting, as recommended by Prados (1989).

The potential daily water for artichoke was calculated based on the pan evaporation method. Average monthly data of class A pan evaporation for the experimental site was obtained from the climatological station as mm per day. The final water requirement was estimated using the formulas presented in Table 3.3 according to Allen *et al.* (1998).

Table 3.3 Calculation of amount of water required by the crop according to Allen *et al.* (1998)

$ET_o = E_{pan} \times K_p$
$CU = ET_o \times K_c$
$WR = CU \times L\%$

Where:

ET_o: Reference evapotranspiration
E_{pan}: Pan evaporation in mm daily
K_p: Pan coefficient 'constant'
CU: Water consumption
K_c: Crop coefficient 'variable 0.5:1.2, depending on plant growth stage'
L%: Leaching factor '1.25%'
WR: Water requirement 'mm per m^2 daily'

The final daily water requirement was calculated based on monthly averages of E_{pan}, K_p = 0.85 and K_c = 0.6, 0.7, 0.8, 0.9, 1.2, 1.1 and 1.0 in Sep., Oct., Nov., Dec., Jan., (Feb. and Mar.) and (Apr. and May), respectively.

According to the previous calculations, four drip irrigation treatments differing in the daily application rate were used. The amount of water required as calculated based on class A pan was compared with two lower irrigation rates and one excess irrigation rate (Table 3.4).

Treatments:

T1: 50% of pan (as a drought treatment)

T2: 75% of pan (as a moderate treatment)

T3: 100% of pan (as a control treatment)

T4: 125% of pan (as an excessive treatment)

Table 3.4 Calculated amount of daily irrigation rate for each treatment based on class A Pan

Month	mm m^{-2} day^{-1}			
	50% of Pan	75% of Pan	100% of Pan	125% of Pan
September	0.434	0.651	0.869	1.086
October	0.576	0.865	1.153	1.441
November	0.536	0.803	1.071	1.339
December	0.516	0.775	1.033	1.291
January	0.528	0.792	1.056	1.320
February	0.926	1.388	1.851	2.314
March	1.657	2.485	3.313	4.142
April	2.950	4.425	5.900	7.375
May	3.313	4.970	6.627	8.284

3.1.4 Evaluating parameters

3.1.4.1 Growth parameters

The following measurements of vegetative growth characters were done 90, 120 and 150 days after planting:

1. Plant height (cm)

   The height of plants was measured from the soil surface up to the tip of the longest leaf.

2. Number of leaves per plant
3. Leaf area (cm^2)

   Leaf area was determined using the LI-3100 Area Meter (LI-COR, Inc. Lincoln, Nebraska, USA).

4. Leaf fresh weight (g)
5. Leaf dry weight (g) after drying 3 days at 70°C
6. Leaf chlorophyll content (SPAD)

The content of total chlorophyll was measured using a Minolta Chlorophyll Meter (SPAD-501).

As representative sample, the 4th-youngest leaf was taken to determine leaf area, fresh and dry weight as well as chlorophyll content.

3.1.4.2 Yield and yield components

1. Early yield was determined as weight and bud number per plant from the start of harvest until the end of February.
2. Total yield was recorded as weight and bud number per plant and per ha from the beginning of harvest until the end of season.

3.1.4.3 Bud traits

The weight, length and diameter of each bud as well as the weight of edible part were evaluated in February (main buds) and in April (secondary buds).

3.1.4.4 Water measurements

1. Amount of drained water (mm m^{-2})

   During the growth of crop, any excess of water was collected from each lysimeter weekly in order to assess the monthly drained water.

2. Electrical conductivity of the drained water (EC, dS m^{-2})
3. Actual crop evapotranspiration (ET_c, mm m^{-2})

   Actual crop evapotranspiration was calculated on a monthly base, mm m^{-2} $month^{-1}$ as water supplied - water drained = actual evapotranspiration from the crop (the net consumption).

4. Actual crop coefficient (K_c)

   The measured values of actual crop evapotranspiration (ET_c) for each month was compared to the values of reference evapotranspiration (ET_o) and actual K_c calculated as $K_c = ET_c/ET_o$ according to Allen *et al.* (1998).

5. Water use efficiency (WUE, g l^{-1})

   Water use efficiency was calculated as g bud yield per liter water supplied.

3.2 Fertilization experiment

3.2.1 Experimental site

The fertilization experiments were conducted in 2000 and 2001 at the Research Station Dürnast (48° 24' N, 11° 42' E, and at an altitude of 372 m a.s.l.), Chair of Vegetable Science, Center of Life Sciences Weihenstephan, Technische Universität München, Freising in the southern part of Germany.

Main weather data for the site as average monthly average temperatures (Temp.), relative humidity (RH), total rate of rainfall and sunshine hours are presented in Table 3.5.

Table 3.5 Average values of main weather parameters in Freising (historical data for 30 years)

Month	Temp. (°C) Mean	Rainfall (mm) Total	Sunshine (h) Total	RH (%) Mean
January	-1.4	41.1	58.3	81.0
February	-0.3	37.1	86.3	70.0
March	3.7	44.9	131.0	69.0
April	7.2	54.8	159.6	58.5
May	12.4	77.5	214.2	54.0
June	15.1	97.5	203.3	53.0
July	17.0	108.8	227.3	57.5
August	16.7	86.2	220.6	53.5
September	12.8	71.9	165.5	73.0
October	7.9	55.6	112.7	76.0
November	2.7	58.4	63.2	81.0
December	0.0	51.7	48.4	83.5
Total/Mean	7.82	785.5	1690.4	67.5

Source: Deutscher Wetterdienst (DWD), Weihenstephan Station, Freising, Germany

The soil of the experimental field is a silty-loam with 16% clay, 66% silt and 18% sand with a bulk density of 1.4 kg/l.

The chemical properties of the experimental soil are given in Table 3.6.

Table 3.6 Chemical properties of the experimental soil at the research station Dürnast

pH	EC [dS m^{-1}]	$CaCO_3$ [mg $100g^{-1}$	Anions [mg $100g^{-1}$]			Cations [mg $100g^{-1}$]	
			NO_3	P	Cl	Ca	K
6.40	0.54	80.4	1.28	8.0	6.0	7.4	19.0

3.2.2 Materials

The experiment was arranged in a randomized complete block design (RCBD) with three replications. The plot areas were 22.5 and 36.0 m^2 containing 25 and 40 plants in both seasons, respectively. During soil preparation, 50 kg N (Calcium Ammonium Nitrate 27% N), 80 kg P_2O_5 ('Novaphos' 23%P_2O_5 + 8% S) and 80 kg K_2O ('Kalimagnesia' 30% K_2O + 10% MgO + 17% S) per ha as basic fertilization were soil-incorporated before planting. Plastic soil mulch was used and the plants were covered with an unwoven polypropylene fleece (17 g m^{-2}) until mid of May to protect against late frost.

Green Globe, a seed-propagated artichoke cultivar (Juliwa, Heidelberg, Germany), was planted. To assure good germination, wet seeds were incubated at 25°C for 2 days. Respectively, in both seasons, seeds were sown on 01.03.00 and 02.03.01 in trays with 7x11 cells using the white-peat substrate TKS1 (pH: 5.0-6.5, N: 50-300, P_2O_5: 80-300 and K_2O: 80-400 mg/l, produced by Floragard Vertriebs GmbH für Gartenbau). The trays were held in the greenhouse at day/night temperatures of 20/18°C. Four weeks later, each seedling was transferred into 10-cm pots filled with TKS1. Seedlings were irrigated on ebb-flood tables with nutrient solution (1g l^{-1} of Flory 9 Hydro NPKMg, 17-7-22-6) for best transplant quality. At the end of April, the eight-week old seedlings were transplanted into the field after one-week adaptation outdoors under a shelter. Each two plants were placed 60 cm apart on the ridge and 150 cm between the ridges, resulting in planting density of approximately 11000 plants per ha. Harvesting started in mid July and continued until the first week of September.

3.2.3 Experimental plan

Two trials were conducted to evaluate artichoke growth and productivity under different fertilizer combinations for two seasons. Seven different proportions of N and K in the range of 200 to 400 kg ha^{-1} for N and 300 to 500 kg ha^{-1} for K_2O were used. Little modification was done for treatment rates in the second season. The treatments are specified in Table 3.7.

Treatments:

Table 3.7 Rates of total N and K_2O, applied as basal application before planting and in 10 constant fertigation rates in the control (T1) and dynamic rates in T2 to T7 in both seasons

Treatments	Total kg N ha^{-1}		Total kg K_2O ha^{-1}	
	1st season	2nd season	1st season	2nd season
T1: 'Control'	300		400	
T2:	300		400	
T3:	200	250	400	
T4:	400		400	
T5:	200	350	300	400
T6:	300		300	350
T7:	300		500	450

The fertilizers 'Kalksalpeter' (Calcium Nitrate, Ca $(NO_3)_2$, 15.5% N) and 'Krista-K' (Potassium Nitrate, KNO_3, 46% K_2O + 13.5% N) were used as N and K sources. Dripper fertigation started two weeks after transplanting for all seven treatments by using T-tape laterals (TSX 520-30-340, T-Systems, Europe). Fertigation occurred weekly for 10 weeks with gradually decreasing doses of N and increasing doses of K_2O, (dynamic rates for T2:T7). As a control, the amount of 300 kg N ha^{-1} and 400 kg K_2O ha^{-1} was applied weekly at constant rates (T1). The plants were treated with the same rate of N (300 kg N ha^{-1}) and K (400 kg K_2O ha^{-1}) in both T1 (control) and T2 (see Table 3.7).

Figure 3.1 shows the weekly doses application of N and K_2O in T1 (constant doses) and T2 (dynamic doses).

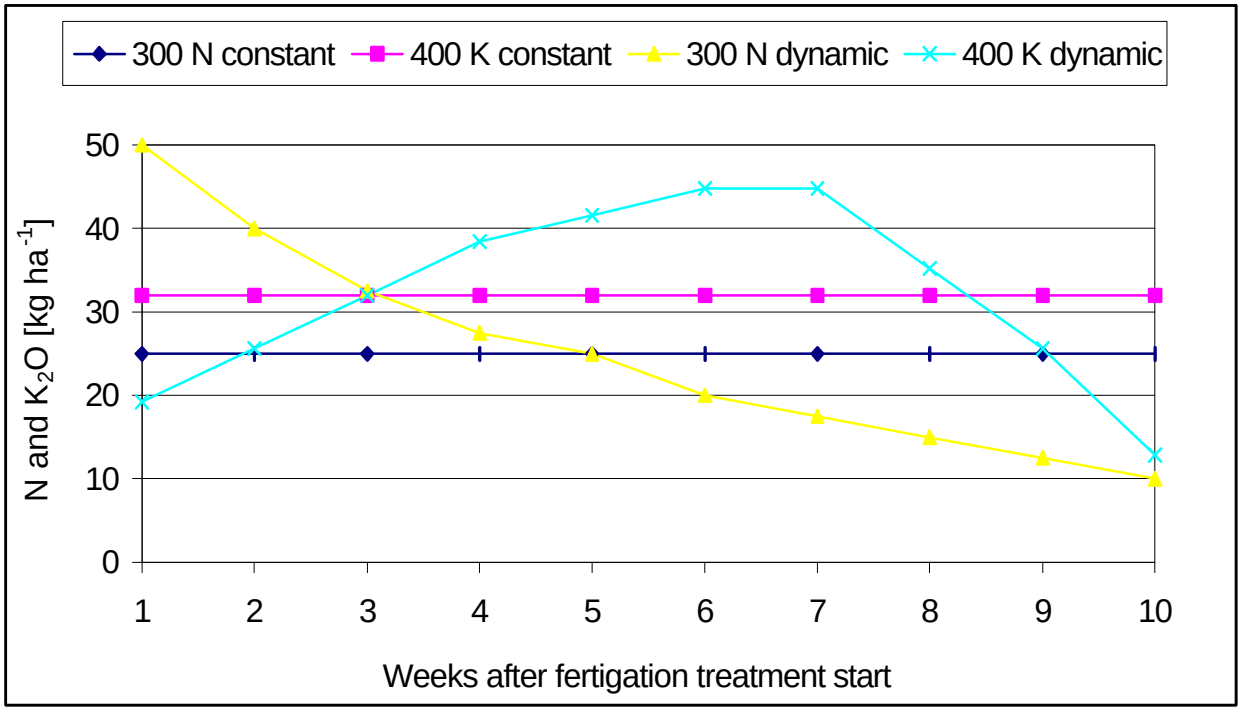


Figure 3.1 Comparison between weekly doses of N and K_2O application in T1 (constant doses) and T2 (dynamic doses)

3.2.4 Evaluating parameters

Representative soil samples from the soil surface (0-30 cm) and subsurface layer (30-60 cm) were collected fortnightly. At the same time, samples from the fourth leaf and subsequently from main and secondary buds were evaluated. The first samples were taken 2 weeks after the first fertigation one day before the next fertigation was made.

Growth characters such as plant height (cm), number of leaves per plant, leaf area (cm^2), leaf fresh weight (g), leaf dry weight (g) and leaf chlorophyll content (SPAD), yield and yield components, as well as bud traits were evaluated as described in chapter 3.1.4, except early yield was calculated for the first three harvests.

3.3 Salinity experiments

3.3.1 Experimental site

Two experiments were conducted in 2002 at the Research Station Dürnast, Chair of Vegetable Science, Center of Life Sciences Weihenstephan, Technische Universität München, Freising in southern Germany. The investigation was carried out in an environmentally controlled greenhouse. Maximum greenhouse air temperature ranged from 16 to 20°C, with a minimum night temperature of 14°C. Relative humidity ranged from 60 to 75%.

3.3.2 Materials

Globe artichoke (cv. Green Globe) seeds were wet and incubated at 25°C for 2 days to enhance the germination. Subsequently, seeds were sown on March 1st in trays with 7x11 cells using TKS1 as substrate. The trays were placed on ebb-flood tables in the greenhouse and irrigated with nutrient solution of Flory 9 hydro (NPKMg, 15-7-22-6) according to demand. Four weeks later, seedlings were transferred into 10-cm plastic pots (1 plant per pot) filled with TKS1 for Exp. B. At the same time seedlings for Exp. A were transplanted directly in 13-cm pots, filled with sandy soil. The seedlings in the 10-cm pots were irrigated on ebb-flood tables with solution of Flory 9 hydro (1g l^{-1}) for another four weeks. Afterwards, eight-week old seedlings were transferred into sand-filled plastic pots of 10-l volume (Exp. B). Seedlings in 13-cm pots and in 10-l pots were fertigated with full nutrient solution adjusted to pH 5.5-6.5 and EC values of approximately 1.5 according to Hoagland and Arnon (1950). Deionized water was used for preparing the solution. This solution contained the macronutrients NO_3, NH_4, P, K, Ca, Mg and SO_4 and micronutrients Fe, Mn, Zn, B, Cu and Mo at 14.0, 2.0, 2.0, 6.5, 3.75, 1.0 and 1.0 mmol l^{-1} and 15, 10, 5, 25, 0.75 and 0.50 µmol l^{-1}, respectively.

Particle-size < 0.8 mm of sandy texture (93.0% sand, 6.2% silt and 0.8% clay) was used in both experiments, which was free of Na and Cl ions (see chemical analysis in Table 3.8).

Table 3.8 Chemical analyses of sand used in salinity experiments

pH	EC [dS m^{-1}]	$CaCO_3$ [mg $100g^{-1}$]	K [mg $100g^{-1}$]	P [mg $100g^{-1}$]
7.8	0.27	0.0	3.0	3.0

3.3.3 Experimental plan

3.3.3.1 Salt tolerance of seedlings (Experiment A)

Primary experiment was conducted to evaluate artichoke plants during the seedling stage under salinity stress. Four-week old artichoke seedlings were transplanted into sand-filled plastic pots (13-cm diameter). All pots were put on tables and dripper irrigated with a full nutrient solution (see chapter 3.3.2) in a closed system (0.5 l per plant daily). One week later, the three different salinity levels were established in addition to the control and evaluated over four weeks. NaCl was added to the nutrient solution on April 1st at 0, 50, 100 or 150 mmol l^{-1}. The final electrical conductivity (EC) after applications of NaCl is presented in Table 3.9. After 4 weeks exposure, seedlings were harvested and seedling quality was measured. Treatments were arranged in a randomized complete block design (RCBD) with 3 replications, each plot containing 16 seedlings.

Treatments:

Table 3.9 Doses of NaCl and resulting final electrical conductivity (EC) of nutrient solution for the different salinity treatments

Treatments	NaCl applications		Final EC [dS m^{-1}]
	[mmol l^{-1}]	[g l^{-1}]	
T1: 'Control'	0	0	1.5
T2:	50	2.93	6.5
T3:	100	5.85	10.1
T4:	150	8.78	14.8

3.3.3.2 Promotion of salt tolerance (Experiment B)

Three strategies of additives (anti-salinity) aimed to ameliorate the adverse effect of salinity were compared to control plants grown under saline and non-saline conditions. The plants were either treated with Ca supplement or with *Bacillus subtilis* and/or a mixture of micronutrients by foliar applications.

- Ca supplement was added at 5 mmol l^{-1} to the saline nutrient solution using $CaCl_2$.
- *Bacillus subtilis,* a biological agent was inoculated into the root zone of plants exposed to saline nutrient solution. *Bacillus subtilis* strain FZB 24 WG was obtained as granulous formulation from FZB Biotechnik GmbH Berlin. This registered water-soluble preparation formulated on cornstarch as carrier contained 10^{11} spores g^{-1}. A pure bacterial spore suspension for application was prepared by dissolving 0.2 g per l of the granulate. For root bacterization, seedling substrate was watered with bacterial spore-suspension (l.0 l per m^2) at two true leaves stage with 0.5 l per pot directly after transplanting into the 10-l pots. Then, application of 1g granular product per 500 l of nutrient solution were re-circulating in the closed system.
- The foliar application of the micronutrients Fe, Mn and Zn was given as a mixture of 60, 320 and 220 mg per l, respectively, as 1g of Flory 72 (6% EDDHA-chelated Fe), Manganese sulfate (32% Mn) and Zinc sulfate (22% Zn) per l. The solution was sprayed four times in 15 days intervals (200 ml per plant) with control of pure water sprays.

The two-factors experiment was designed as split plot. Eight treatments, as factorial experiment were laid-out in three replications. Each plot contained 8 plants. The four 'nutrient solution' treatments, e.g., non-saline, saline, saline with extra Ca and saline with *Bacillus subtilis* (Factor A) were assigned to the main-plots, but not randomized within blocks due to the technical realization, while the micronutrient treatment and the respective control (Factor B) were randomized and occupied the sub-plots.

Eight-week old seedlings of good quality were transferred into sand-filled plastic pots (10 l). For a good plant establishment, all seedlings were first fertigated with full nutrient solution adjusted to pH 5.5-6.5 and EC value of approximately 1.5 in a closed system with re-circulating the nutrient solution using a rotary pump. Four weeks later a solution of 50 mmol l^{-1} NaCl was applied, resulting in a final EC value of 6.5 dS m^{-1} of the nutrient solution.

3.3.4 Irrigation system and maintenance of nutrient and NaCl concentrations

- The nutrient solution of each treatment was applied in a separate re-circulating system as described in Figure 3.2.

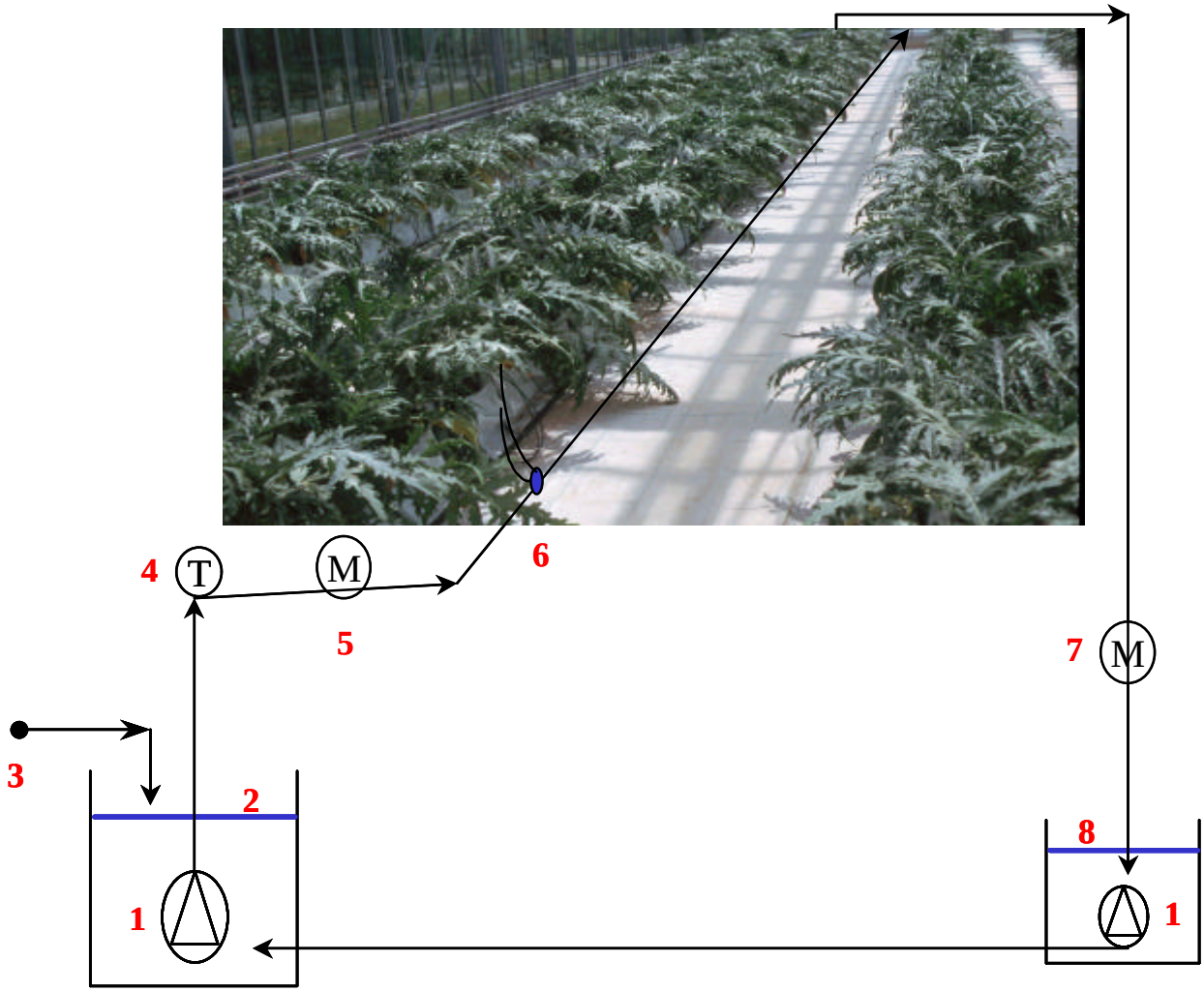


Figure 3.2 The re-circulating system of nutrient solution for artichoke plants in the greenhouse
Consisted of: 1: Rotary pump 2: Tank of nutrient solution 3: Source of fresh water 4: Timer 5: Water meter for input of nutrient solution 6: Drippers 7: Water meter for output of drained water 8: Tank to collect drain water for re-circulation

- The nutrient solution was applied four times (between 9^{00}:15^{00} hour) daily for 15 minutes resulting in application of 4 l per plant and 30-50% drainage rate. Two months after transplanting, irrigation frequency was increased to 8 times (between 9^{00}:16^{00} hour) per day resulting in 8 l per plant corresponding to plant development and increased temperature and radiation as well as leaching requirement in order to maintain the drainage rate. Fresh water was refilled automatically according to consumption. To maintain the adequate EC and pH of the nutrient solution, EC and

pH were measured daily and adjusted by adding stock-nutrient solution and sulfuric acid, respectively.

- NaCl was added to the nutrient solution to adjust EC to 6.5 dS m^{-1}. Every two weeks, the content of the nutrient solution and the recipe of the nutrient-stock solution were adjusted according to the complete nutrient and Na and Cl ions analysis of the drainage water. One month after treatments start, the entire nutrient solution was renewed after having flushed the system with deionized water.

3.3.5 Evaluating parameters

3.3.5.1 Experiment A:

Four weeks after seedling exposure to treatments, all plants of each plot were harvested for evaluation. Samples were taken from both shoots and roots as well as from soil for chemical analyses:

1. Seedling quality: shoot height, number of true leaves, shoot fresh and dry weight, leaf area per seedling and root dry weight as described in chapter 3.1.4.
   For the determination of root dry weight, the sand was washed and rinsed off the roots and roots were dried at 70°C for 3 days.
2. Nutrient status: Cl, Na, K, Ca and Mg in shoots, roots and soil as well as EC of soil.

3.3.5.2 Experiment B:

Vegetative growth and physiological characters at two weeks intervals, yield and bud traits, water consumption and nutrient status were measured.

1. Growth characters: Plant height, number of leaves per plant and dry weight of the 4^{th}-youngest leaf were determined as described in chapter 3.1.4. Biomass dry weight of total shoots and roots per plant were evaluated at the end of the experiment.
2. Physiological characters: Photosynthetic activity, transpiration rate and stomatal conductance of fully expanded and well light exposed leaves were measured with a Lci portable photosynthesis system, porometer model (ADC BioScientific Ltd. Hoddesdon, Herts, England). The measurements were done at sunny days approximately at 2 weeks intervals.

3. Yield: Buds were harvested at one-week intervals. Early (first two harvests) and total yield were determined for weight and number of buds per plant. The marketable yield was calculated after exclusion of buds that have black spot (non-marketable).
4. Water: The input and output quantities of water were recorded daily for the supplied and drained water to calculate the net consumption of water during the growth season. Water use efficiency was calculated as g bud yield per l supplied water.
5. Bud traits: Weight, length and diameter of each bud as well as weight of the edible part were determined from representative samples of main and secondary buds.
6. Nutrient status: Cl, Na, K, Ca, Mg, Fe, Mn, and Zn in plant parts (4^{th}-youngest leaf, shoots, roots and buds) and soil as well as the EC value of the soil were determined fortnightly.

3.4 Chemical analysis

3.4.1 Sample preparation

3.4.1.1 Plant material

For chemical analyses, the 4^{th}-youngest leaf, shoots, and roots as well as main and secondary buds of the artichoke plants (cultivation see chapter 3.1.2, 3.2.2 and 3.3.2) were sampled. The material was dried for three days in an oven at 70°C. Afterwards, the samples were ground with a Culatti MFC grinder equipped with a 1-mm sieve, packed airtight in brown glass bottles and stored in a desiccator in the dark until analysis.

3.4.1.2 Soil

Two kinds of soil were used in the experiments. For experiments in the greenhouse, sand was free of Na and Cl ions (chemical properties see Table 3.8). Soil samples from the field experiments (chemical properties see Table 3.6) were collected from two layers (see chapter 3.2.4) of the experimental field at the Research Station Dürnast. For nitrate measurement the field soil samples were stored immediately in a freezer. For analysis, defrozen samples were sieved (5-mm-width). Nitrate was extracted by 0.0125 M $CaCl_2$-solution in a ratio of 40 g soil to 200 ml solution (Houba *et al.*, 1986), and analyzed by ion chromatography with a HPLC. For investigation of other mineral nutrients, air-dried soil was used. Potassium was extracted by Calcium-Acetate-Lactate (CAL) solution at a ratio of 5 g soil to 100 ml CAL-solution according to Schüller (1969).

For Ca and Cl determination 25 g sandy soil were extracted with 125 ml of distilled water for about 1 hour. The content of the mineral nutrients was analyzed by flame atomic absorption spectroscopy (flame AAS) (VARIAN Spectra AA 100) and the Cl content titrimetrically as described in chapter 3.4.4.2. Moreover, for analysis of Na and K in sandy soil the samples were extracted with a double lactate (DL) solution according to the method of VDLUFA (1997). The EC value was measured in soil:distilled water ratio (1:10) after shaking for 60 minutes using EC meter (GMH 3410 CE, Greisinger electronic).

3.4.2 Total nitrogen (N) and calculation of protein

Total nitrogen was determined in the leaves and edible parts of the buds according to a modified method of Kjeldahl (Horneck and Miller, 1998). The rate of crude protein in the edible part of the buds was calculated from the total N-content corrected with an appropriate conversion factor according to the correlation (AOAC, 1975):

$$\% \text{ Crude protein} = \% \text{ N} \times 6.25$$

3.4.3 Total fiber

The method of measurement of the crude fiber fraction based on the determination of the mass lost after dry ashing of the sample before both acid and alkaline treatment. The mass lost corresponds to the content of the crude fiber in the sample.

For analysis 1.0 g of the dry sample of the edible part was treated first with boiling 0.13 mmol l^{-1} H_2SO_4 and subsequently with a solution of boiling 0.23 mmol l^{-1} KOH. After filtration the residue was washed, dried and weighed and finally ashed in a muffle furnace at a temperature of 500°C for four hours (Anonymous, 1992). The analysis was carried out with a Fibertec System M apparatus comprises in a Tecator 1017 hot extractor and a Tecator 1021 cold extractor.

3.4.4 Mineral nutrients

For sample preparation the organic matter of the plant material has to be removed. Therefore, samples of 2.0 g were weighed in aluminium crucibles and ashed in a muffle furnace at temperatures of 500 to 550°C for six hours. At the end of the ashing period, the crucibles were placed out of the muffle furnace, cooled and digested with conc. hydrochloric acid (HCl). Afterwards, the HCl was fumed off and the remaining ash was

taken up with 5 ml of 10% HNO_3. The samples were transferred to 100 ml volumetric flasks and filled up with a solution of 10% HNO_3.

3.4.4.1 Cations

The solutions from chapter 3.4.4 were filtered (S & S, ashless 589^2 white ribbon) and the mineral nutrients such as K, Mg, Ca, Na, Fe, Mn, and Zn were measured by the flame AAS (VARIAN Spectra AA 100).

3.4.4.2 Chloride (Cl)

5.0 g of the ground plant samples were extracted with exactly 250 ml of distilled water in a shaker for 30 min. All samples were analyzed in duplicates. The sample solutions were filtered (S & S, ashless 589^2 white ribbon) and the chloride ions were determined by titration according to the method of VDLUFA (1983). From each sample three times 50 ml were given in 250 ml-Erlenmeyer flasks adding 50 ml methanol to each as well as 10 drops of a 1% solution of diphenylcarbazone (in ethanol) as indicator. The titration was carried out with a solution of 0.02 N mercury (II) nitrate. The endpoint was reached when the colour changed to pale violet. 1ml 0.02 N mercury (II) nitrate solution corresponds to 0.7092 mg Cl.

3.4.4.3 Total Phosphorous (P)

The content of total phosphorous was measured in the same extracts as described in chapter 3.4.4. Phosphor content was determined photometrically as yellow colored molybdatophosphate at a wavelength of 430 nm using a HITACHI Spectrophotometer, model U-3200 (VDLUFA, 1983).

3.5 Statistical analysis

The obtained data from all studied trials were statistically analyzed using CoStat software package (CoHort Software, 1986). The treatment effects were evaluated by analysis of variances considering the RCBD and split plot design of the experiments. The mean values were compared using Duncan's multiple range test at $P < 5\%$ as reported by Gomez and Gomez (1984).

4. RESULTS

4.1 Irrigation experiment

4.1.1 Vegetative growth characters

Data presented in Table 4.1 exhibit the effect of four water regimes on vegetative growth characters, e.g., plant height, number of leaves per plant, fresh and dry weight as well as the area of the 4th-youngest leaf 90, 120 and 150 days after planting during two growing seasons.

Height of plant and number of leaves per plant increased due to the increase of the amount of supplied water from 50% to 100% of pan evaporation in both seasons. No further increases were observed when water was applied at 125% of pan evaporation, with tendency to decrease plant height and number of leaves per plant 120 and 150 days after planting in the 1st season and number of leaves per plant 120 days after planting in the 2nd season.

Application of water at 75 and 100% of pan evaporation resulted in the highest fresh and dry weight as well as the area of 4th-youngest leaf. Treatment of 125% of pan evaporation did not only supply any significant increases but also decreased the dry weight of the 4th-youngest leaf 150 days after planting in the 1st season and 120 and 150 days after planting in the 2nd season.

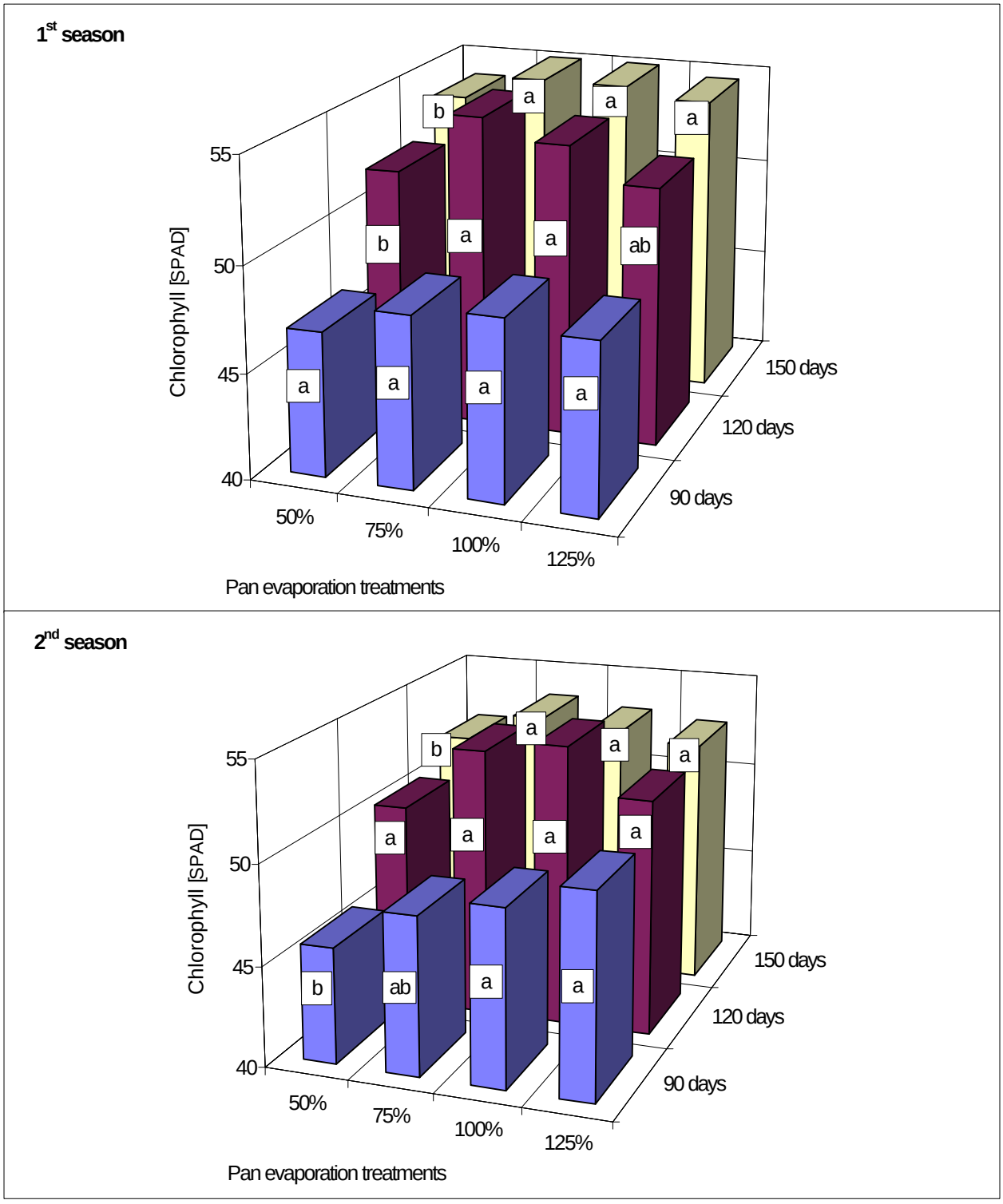
Generally, the lowest water application rate of 50% of pan evaporation was always inferior compared to the other three water treatments concerning all vegetative growth characters during both seasons.

Applied water at 50% of pan evaporation resulted in significant decrease of total chlorophyll content in leaves compared to the other three water treatments in both seasons (Figure 4.1). Generally, chlorophyll content of 4th-youngest leaf did not differ among application rates above 50% of pan evaporation in both seasons. On the other hand, it tended to increase by increasing water application rates 90 days after planting in the 2nd season and to decrease by the highest irrigation rate of 125% of pan evaporation 120 days after planting in the 1st season.

Table 4.1 Effect of different water regimes (application rate according to % pan evaporation) on vegetative growth characters of artichoke plants 90, 120 and 150 days after planting during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

Treatments	Plant height [**cm**]	No. of leaves/plant	Fresh weight of 4th-leaf [**g**]	Dry weight of 4th-leaf [**g**]	Area of 4th-leaf [**cm²**]
1st season					
	90 days after planting				
50% of pan	42.7 b	26.0 b	79.7 b	11.6 a	483.3 b
75% of pan	45.3 ab	29.3 ab	86.0 a	12.9 a	507.0 a
100% of pan	48.3 a	30.3 a	86.3 a	12.7 a	513.3 a
125% of pan	49.0 a	34.3 a	81.7 ab	11.7 a	518.3 a
	120 days after planting				
50% of pan	52.7 c	47.7 b	107.7 b	15.7 a	524.3 b
75% of pan	55.3 bc	54.3 a	116.7 a	17.5 a	537.0 ab
100% of pan	59.7 a	54.7 a	121.0 a	17.3 a	549.7 a
125% of pan	56.0 b	50.7 ab	113.7 ab	16.3 a	543.0 a
	150 days after planting				
50% of pan	69.7 b	60.3 b	93.3 c	14.4 b	486.0 a
75% of pan	74.3 ab	66.7 a	111.7 a	17.7 a	516.0 a
100% of pan	78.3 a	68.3 a	105.7 b	16.5 a	499.0 a
125% of pan	72.3 ab	64.3 ab	102.7 b	16.3 ab	497.0 a
2nd season					
	90 days after planting				
50% of pan	43.3 b	26.3 b	77.3 a	11.0 a	476.7 b
75% of pan	44.7 ab	28.7 ab	80.7 a	11.7 a	492.7 ab
100% of pan	47.3 a	29.3 ab	82.3 a	11.7 a	512.3 a
125% of pan	48.3 a	31.7 a	82.7 a	11.6 a	507.7 a
	120 days after planting				
50% of pan	51.7 b	46.3 b	103.7 b	13.9 b	491.3 b
75% of pan	56.3 a	50.7 a	114.7 a	15.6 a	515.0 a
100% of pan	56.7 a	51.3 a	120.3 a	16.7 a	522.3 a
125% of pan	55.3 a	48.0 ab	111.7 ab	14.8 ab	516.3 a
	150 days after planting				
50% of pan	70.7 b	56.0 c	97.3 b	14.7 c	492.0 a
75% of pan	72.0 b	61.3 b	107.7 a	16.9 a	509.7 a
100% of pan	77.7 a	66.7 a	105.7 a	16.3 ab	515.3 a
125% of pan	75.7 a	65.0 a	108.3 a	16.2 b	518.7 a

Means within each column and sampling date followed by the same letter are not significantly different at $P<5\%$



Means of the same date with the same letter are not significantly different at $P < 5\%$

Figure 4.1 Effect of different water regimes (application rate according to % pan evaporation) on leaf chlorophyll content (SPAD) of artichoke plants 90, 120 and 150 days after planting during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

4.1.2 Bud yield

Application of water at 100% and 50% of pan evaporation resulted in the highest and the lowest total yield of buds per plant (kg) and calculated yield per hectar (ton), respectively, in both seasons and the highest and the lowest early yield, respectively, in the 1st season (Table 4.2). On the other hand, no significant differences in total yield were observed among the three irrigation treatments above 50% of pan evaporation in the 1st season, while early yield in the 2nd season had no response to all four irrigation treatments.

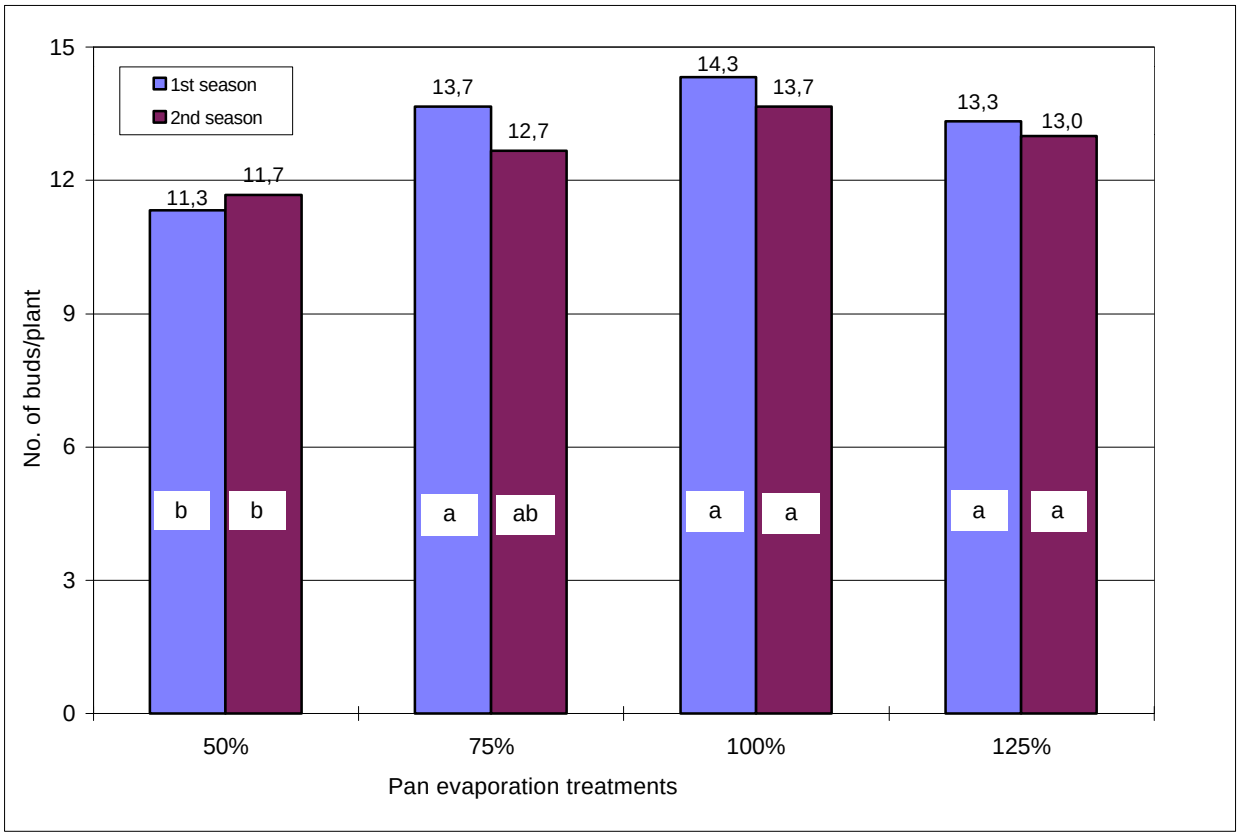
Table 4.2 Effect of different water regimes (application rate according to % pan evaporation) on bud yield of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

Treatments	Early yield		Total yield	
	[kg/plant]	[t/ha]	[kg/plant]	[t/ha]
1st season				
50% of pan	0.59 b	3.94 b	2.20 b	14.64 b
75% of pan	0.77 ab	5.13 ab	3.00 a	19.98 a
100% of pan	0.84 a	5.60 a	3.16 a	21.07 a
125% of pan	0.61 b	4.03 b	2.88 a	19.17 a
2nd season				
50% of pan	0.51 a	3.41 a	2.22 c	14.79 c
75% of pan	0.70 a	4.65 a	2.54 bc	16.91 bc
100% of pan	0.64 a	4.24 a	2.82 a	18.78 a
125% of pan	0.50 a	3.25 a	2.58 b	17.18 b

Means within each column and season followed by the same letter are not significantly different at $P<5\%$

The lowest total number of buds per plant was obtained from the lowest water application rate of 50% of pan evaporation in both seasons (Figure 4.2). The total number of buds per plant was positively influenced by increasing water application with the highest number in the treatment with 100% of pan evaporation in both seasons, followed by treatment with

75% in the 1st season and by treatment with 125% in the 2nd season without significant differences.



Means of the same season with the same letter are not significantly different at $P<5\%$

Figure 4.2 Effect of different water regimes (application rate according to % pan evaporation) on total number of artichoke buds per plant during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

4.1.3 Water measurements

The data presented in Table 4.3 show that the quantity of drained water increased with increasing the amount of supplied irrigation water. The highest drained water was recorded with the highest irrigation treatment of 125%, followed by 100% of pan evaporation in both seasons. Moreover, the lowest irrigation treatments of 50% in both seasons and 75% of pan evaporation in the 1st season did not produce any drained water. Also, net consumption of water by plants was positively affected with increasing water application rates.

In contrast, the electric conductivity (EC) of drained water decreased gradually by increasing the amount of supplied water from 75 to 125% of pan evaporation.

Table 4.3 Effect of different water regimes (application rate according to % pan evaporation) on water measurements of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

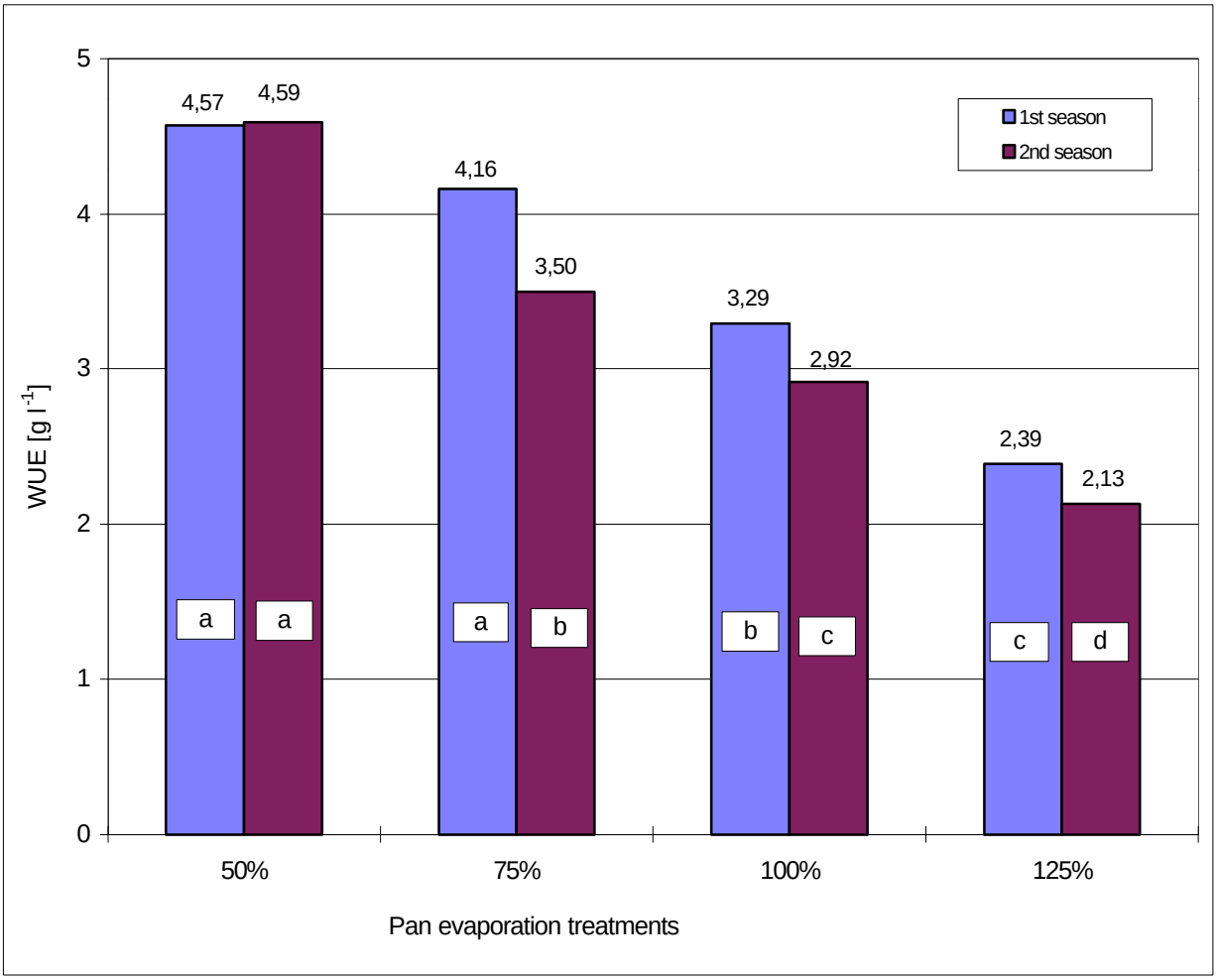
Treatments	Supplied water [**l m^{-2}**]	Drained water [**l m^{-2}**]	EC of drained water [**dS m^{-1}**]	Net consumption [**l m^{-2}**]
1st season				
50% of pan	320.5	0.0	....	320.5
75% of pan	480.7	0.0	....	480.7
100% of pan	640.9	40.5	3.5	600.4
125% of pan	801.2	70.0	3.3	731.1
2nd season				
50% of pan	322.1	0.0	....	322.1
75% of pan	483.1	21.2	4.0	462.0
100% of pan	644.2	68.0	4.0	576.2
125% of pan	805.2	93.4	3.8	711.8

With regard to the effect of applied rates of water on water use efficiency (WUE) as g yield of buds per l supplied water, it is evident from Figure 4.3 that the water use efficiency increased with reducing application rates from 125 to 50% of pan evaporation during both seasons. There was no significant difference between 50 and 75% irrigation treatments in their effect on WUE in the 1st season.

The results presented in Figure 4.4 depict the effect of different supplied water regimes on the actual crop coefficient (K_c) during the growing period and their comparison with calculated K_c. The obtained results show that actual K_c of artichoke increased with increasing amounts of supplied water from 50 to 125% of pan evaporation during both seasons. However, actual K_c was lower than calculated K_c in the first part of the growing

period from September until November for all irrigation treatments. It remained lower for 50 and 75% but was corresponding for 100% of pan evaporation until the end of growing period. It was higher for 125% of pan evaporation treatment.

Generally and irrespective of the different water regimes, actual K_c of artichoke plants gradually increased with increasing vegetative growth from September and reached its maximum during January. There was a tendency of decreasing K_c in February. Subsequently, K_c remained almost constant with slight variations during spring until the end of the growing season.



Means of the same season with the same letter are not significantly different at $P<5\%$

Figure 4.3 Effect of different water regimes (application rate according to % pan evaporation) on water use efficiency (WUE) as g bud per l supplied water during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

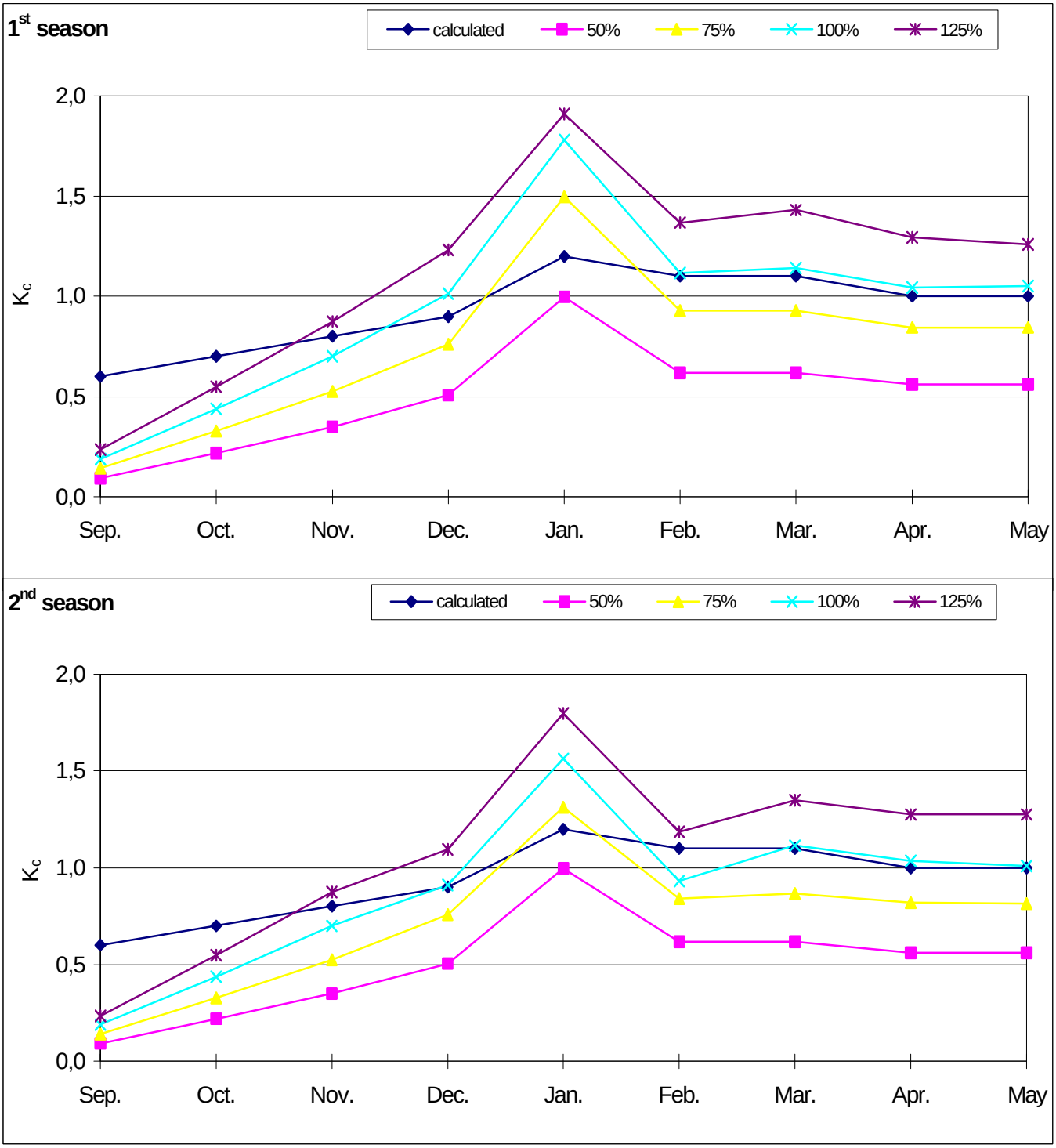


Figure 4.4 Comparison between the calculated and the actual crop coefficient (K_c) of artichoke plants according to different water regimes (application rate according to % pan evaporation) during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

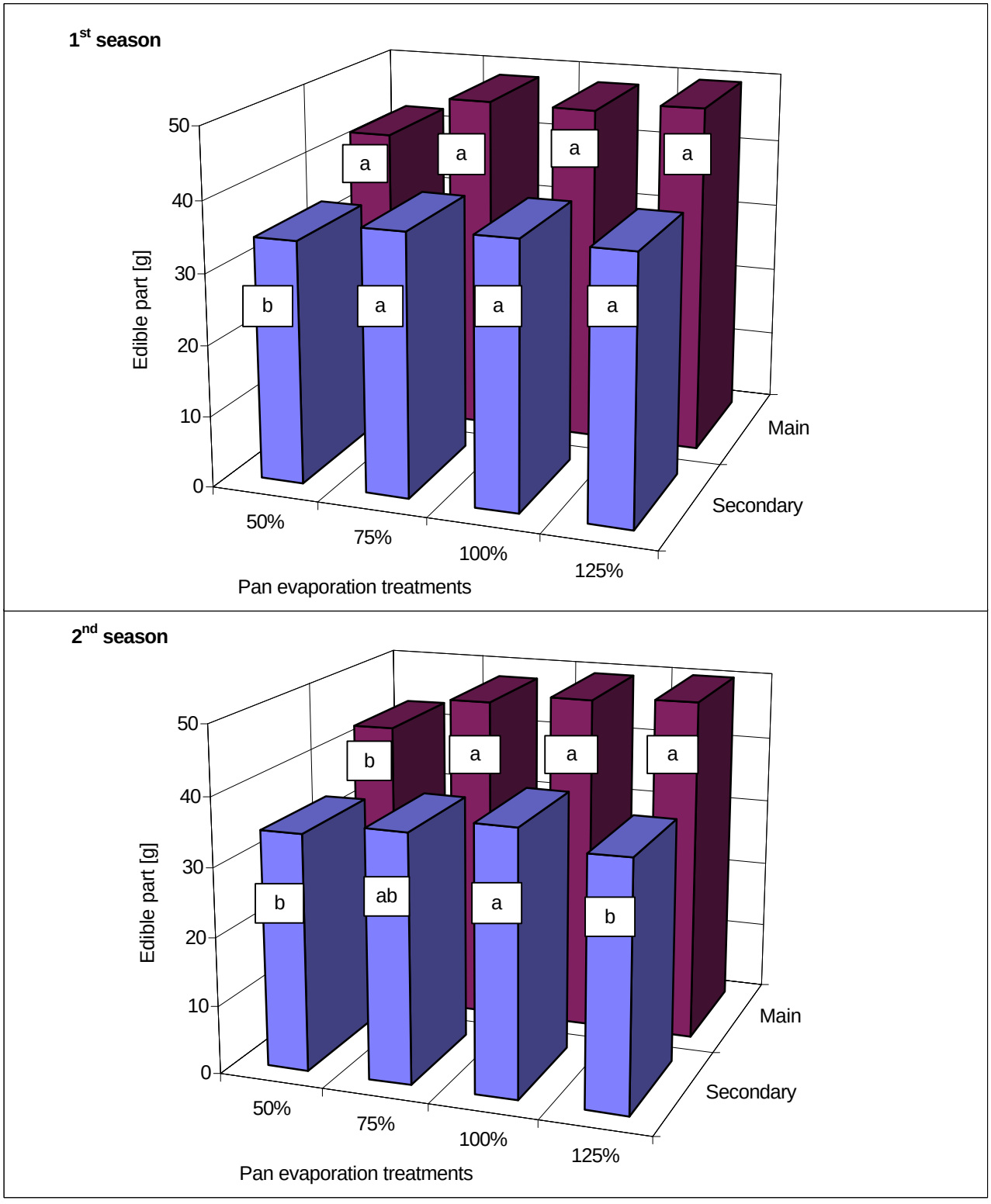
4.1.4 Bud traits

Morphological-physical traits for main and secondary buds of artichoke as well as weight of the edible part are presented in Table 4.4 and Figure 4.5, respectively. The results reveal that the lowest values of all measurements such as weight, length and diameter of both main and secondary buds (Table 4.4) as well as the weight of edible part (Figure 4.5) were always obtained by the lowest water treatment of 50% of pan evaporation in both seasons. Increasing supplied water rates to more than 75% of pan evapotranspiration did not result in any significant increases in main and secondary bud traits as well as in weight of the edible part.

Table 4.4 Effect of different water regimes (application rate according to % pan evaporation) on the traits of main and secondary buds of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

Treatments	Main bud			Secondary bud		
	Weight [**g**]	Length [**mm**]	Diameter [**mm**]	Weight [**g**]	Length [**mm**]	Diameter [**mm**]
1st season						
50% of pan	224.2 b	88.7 b	81.3 a	187.4 c	82.3 c	75.7 b
75% of pan	256.5 a	94.3 a	83.3 a	207.3 b	88.0 a	80.3 a
100% of pan	252.6 a	95.7 a	82.7 a	211.6 a	90.0 a	82.3 a
125% of pan	260.1 a	95.3 a	84.0 a	208.6 b	86.7 b	79.7 a
2nd season						
50% of pan	219.9 a	86.0 b	80.3 a	179.2 b	82.3 a	76.9 b
75% of pan	236.2 a	89.3 ab	81.7 a	191.9 a	84.3 a	79.7 a
100% of pan	240.5 a	91.3 a	82.7 a	198.4 a	85.7 a	82.0 a
125% of pan	251.3 a	92.0 a	83.3 a	189.8 a	83.3 a	80.0 a

Means within each column and season followed by the same letter are not significantly different at $P<5\%$



Means with the same letter are not significantly different at $P<5\%$

Figure 4.5 Effect of different water regimes (application rate according to % pan evaporation) on weight of edible part of main and secondary buds of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

4.1.5 Chemical composition

The lowest content of total N in the 4th-youngest leaf correlated with the lowest water application by the treatment with 50% of pan evaporation (Table 4.5). On the other hand, increasing of application water to 75 or 100% of pan evaporation resulted in the highest content of total N in the 4th-youngest leaf in both growing seasons without statistical differences between the both treatments. In contrast, there was a tendency to decrease the content of total N in the 4th-youngest leaf by the highest application water at 125% of pan evaporation. However, no statistical differences in the content of total N in the 4th-youngest leaf ware found among all irrigation treatments 90 and 120 days after planting in the 2nd season and the 1st one, respectively.

The highest content of N and crude protein in the edible part (see Figure 4.6) was shown by the 75 and 100% treatments. Meanwhile, the lowest content of N and crude protein was obtained by the treatment with 50% of pan evaporation. However, no statistical differences between the highest (125%) and the lowest (50%) treatments on their effects on the content of total N and crude protein generally in the edible part. The same trend was found in the main buds in the 1st season between the two highest treatments (100 and 125%) and in the secondary buds in the 2nd season among all irrigation treatments.

On the other hand, the content of P in both 4th-youngest leaf and edible part mostly was not affected by the irrigation treatments (Table 4.5).

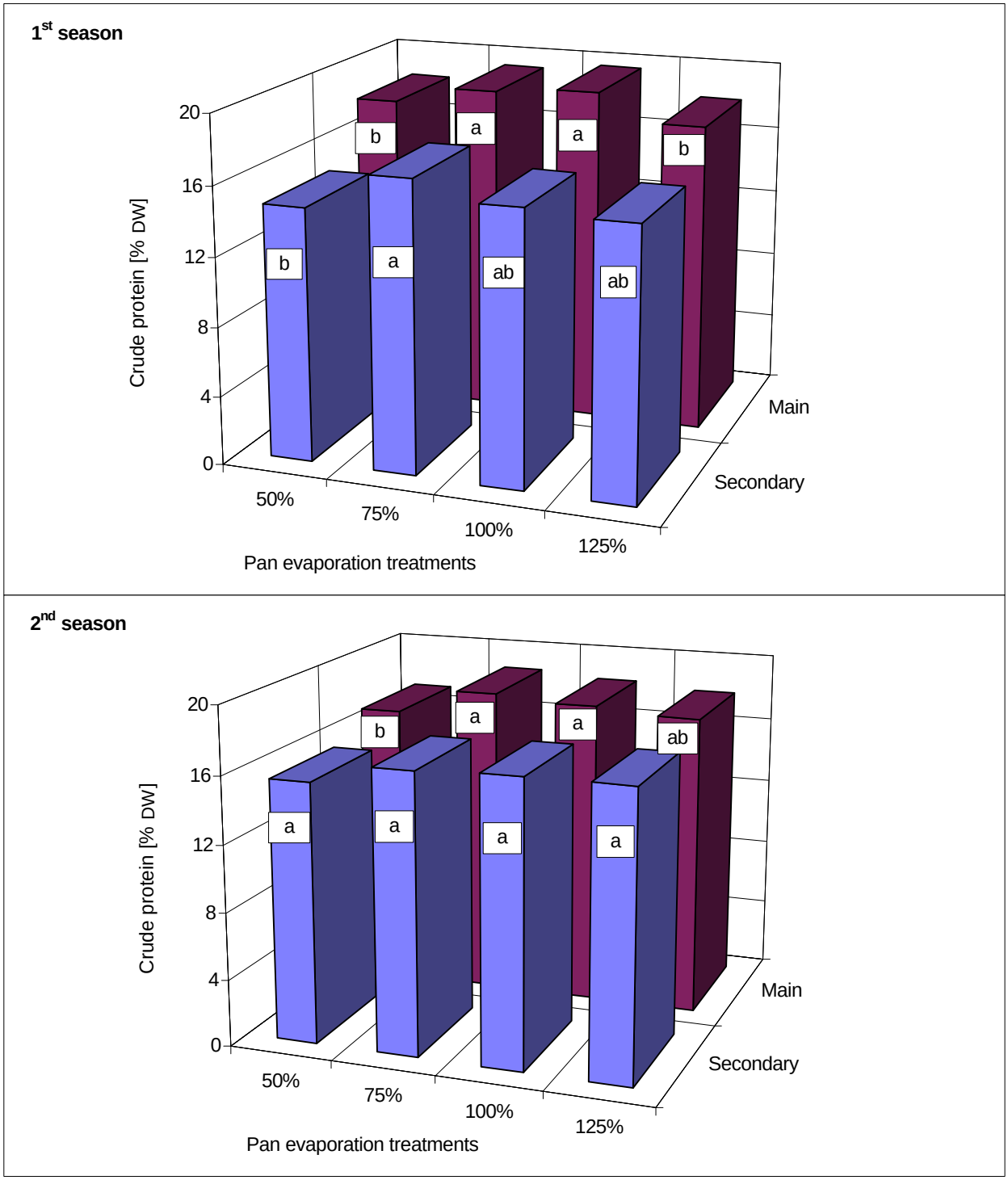
Concerning the content of K in the 4th-youngest leaf, irrigation of 125 and 100% of pan evaporation resulted in the highest K content 120 and 90 days from planting in the 1st season and the 2nd one, respectively, while the lowest K was determined with lowest water treatment (Table 4.5). On the opposite, no significant differences among all irrigation treatments on their effects on the content of K in the 4th-youngest leaf 90 and 120 days after planting in the 1st season and the 2nd one, respectively. On the other hand, K content of the edible part was highest in the main buds of the lowest water treatment (50% of pan evaporation) in the 1st season, while it was not affected by all irrigation treatments in the secondary buds and there were no significant differences in the 2nd season at all.

Total fiber in the edible part of main and secondary buds decreased gradually with increasing water application rates with similar trend in both seasons (Figure 4.7).

Table 4.5 Effect of different water regimes (application rate according to % pan evaporation) on contents of N, P and K in 4th-leaf and edible part of main and secondary buds of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

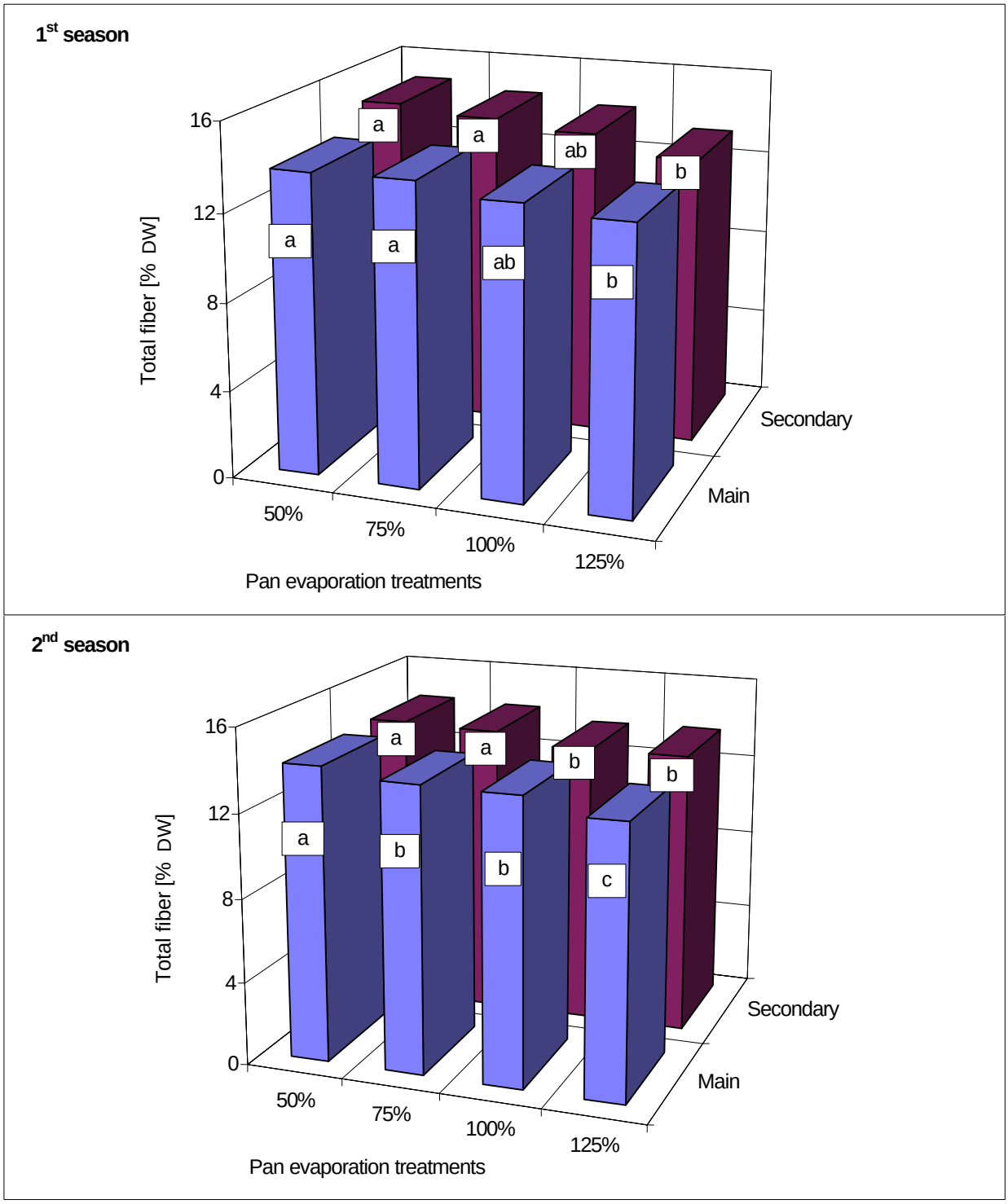
Treatments	4th-leaf			Edible part		
	N [% DW]	P [% DW]	K [% DW]	N [% DW]	P [% DW]	K [% DW]
1st season						
	90 days after planting			Main buds		
50% of pan	3.87 b	0.38 a	3.79 a	2.91 b	0.45 a	3.39 a
75% of pan	4.20 a	0.46 a	3.72 a	3.07 a	0.43 a	3.11 b
100% of pan	4.11 a	0.55 a	3.60 a	3.13 a	0.41 a	3.11 b
125% of pan	3.95 b	0.49 a	3.67 a	2.88 b	0.47 a	3.05 b
	120 days after planting			Secondary buds		
50% of pan	3.31 a	0.47 a	3.67 c	2.35 b	0.45 a	3.41 a
75% of pan	3.48 a	0.44 a	3.61 d	2.69 a	0.36 a	3.69 a
100% of pan	3.55 a	0.48 a	3.91 b	2.53 ab	0.50 a	3.31 a
125% of pan	3.28 a	0.49 a	4.06 a	2.48 ab	0.41 a	3.76 a
2nd season						
	90 days after planting			Main buds		
50% of pan	3.74 a	0.48 a	3.31 c	2.73 b	0.39 a	3.28 a
75% of pan	3.93 a	0.42 a	3.35 bc	2.97 a	0.39 a	3.33 a
100% of pan	3.88 a	0.48 a	3.70 a	2.92 a	0.41 a	2.94 a
125% of pan	3.67 a	0.51 a	3.41 b	2.87 ab	0.34 a	3.01 a
	120 days after planting			Secondary buds		
50% of pan	3.28 b	0.42 a	3.55 a	2.48 a	0.43 a	3.07 a
75% of pan	3.56 a	0.39 a	3.34 a	2.67 a	0.47 a	3.29 a
100% of pan	3.49 a	0.42 a	3.46 a	2.70 a	0.37 b	3.21 a
125% of pan	3.43 ab	0.46 a	3.75 a	2.71 a	0.40 ab	3.33 a

Means within each column and sampling date followed by the same letter are not significantly different at $P<5\%$



Means with the same letter are not significantly different at $P<5\%$

Figure 4.6 Effect of different water regimes (application rate according to % pan evaporation) on crude protein content in the edible part of main and secondary buds of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily



Means with the same letter are not significantly different at $P<5\%$

Figure 4.7 Effect of different water regimes (application rate according to % pan evaporation) on total fiber content in the edible part of main and secondary buds of artichoke during the growing seasons 1998/1999 and 1999/2000 in El-Bossily

4.2 Fertilization experiment

4.2.1 Vegetative growth characters

The response of different vegetative growth characters to differential fertilization of N and K is illustrated in Table 4.6. Resulting data show that the tallest plants 30 days after transplanting (DAT) were obtained by dynamic application of 400 kg ha^{-1} of both N and K_2O in both seasons, however, no significant differences between this treatment and combined application of N at 300 kg N ha^{-1} with K at 300, 400 or 500 kg K_2O ha^{-1} in the 1st season. Also 60 DAT in the 1st season, 400 kg ha^{-1} of both N and K_2O resulted in the tallest plants, without significant differences compared to the combined application of N at 300 kg with K_2O at 400 or 500 kg ha^{-1} in the 1st season. In the 2nd one 60 DAT, 300 kg N and 450 kg K_2O ha^{-1} resulted in the highest plants. In contrast, the shortest plants 30 DAT were produced by the control treatment in both seasons, without significant differences compared to the combined application of 200 kg N with 300 or 400 kg K_2O ha^{-1} in the 1st season and of 250 or 300 kg N with 400 or 350 kg K_2O ha^{-1}, respectively in the 2nd one. The same trend occurred 60 DAT by combined application of 300 kg ha^{-1} of both N and K_2O or N at 200 kg with K_2O at 300 or 400 kg ha^{-1} in the 1st season. In the 2nd one, the control treatment or combined application of 250 kg N with 400 kg K_2O ha^{-1} resulted in the smallest plants 60 DAT.

Number of leaves per plant was not significantly affected by different fertigation rates except at 60 DAT in the 2nd season. The highest number was obtained by application of 300 kg N with 400 or 450 kg K_2O ha^{-1}. The lowest number of leaves per plant was produced with 250 kg N and 400 kg K_2O ha^{-1}, without significant difference compared to control treatment.

The weight of the 4th-youngest leaf was influenced by the rates of N and K during the growing period. Fresh weight was highest 30 DAT with application of 400 kg ha^{-1} of both N and K_2O in both seasons, without significant differences compared to 300 kg N combined with 300 or 400 kg K_2O ha^{-1} in the 1st season. The same high trend occurred 60 DAT by combined application of 300 kg N with 400 kg K_2O ha^{-1} in the 2nd season. The lowest fresh weight was obtained 30 DAT with 200 kg N and 400 kg K_2O ha^{-1} in the 1st season, without significant differences compared to control treatment or N at 200 or 300 kg combined with K_2O at 300 or 500 kg ha^{-1}, respectively. The control treatment produced the lowest leaf

fresh weight in the 2nd season, without significant differences compared to application rates of 250 kg N and 400 kg K_2O ha^{-1} 30 and 60 DAT and of N at 300 or 400 with K_2O at 350 or 400 kg ha^{-1}, respectively 60 DAT.

Dry weight of the 4th-youngest leaf was highest 30 DAT by N at 350 kg combined with K_2O at 400 kg ha^{-1}, without significant differences compared to combined application of 400 kg of both N and K_2O and of N at 300 kg combined with K_2O at 400 or 450 in the 2nd season. At 60 DAT, the highest rates of K_2O (500 and 450 kg ha^{-1} in the 1st season and in the 2nd one, respectively) or moderate rate (400 kg ha^{-1} in both seasons) combined with 300 kg N ha^{-1} resulted in the highest dry weight of the 4th-youngest leaf. In contrast, treatment with control resulted in the lowest dry weight of the 4th-youngest leaf, however there were no significant differences between control and combined application of N at 200 kg with K_2O at 300 or 400 kg ha^{-1} (60 DAT) in the 1st season. In the 2nd one, the same trend occurred with combined application of 250 kg N with 400 kg K_2O ha^{-1} (30 and 60 DAT), of 400 kg of both N and K_2O (60 DAT) and of 300 kg N with 350 kg K_2O ha^{-1} (60 DAT).

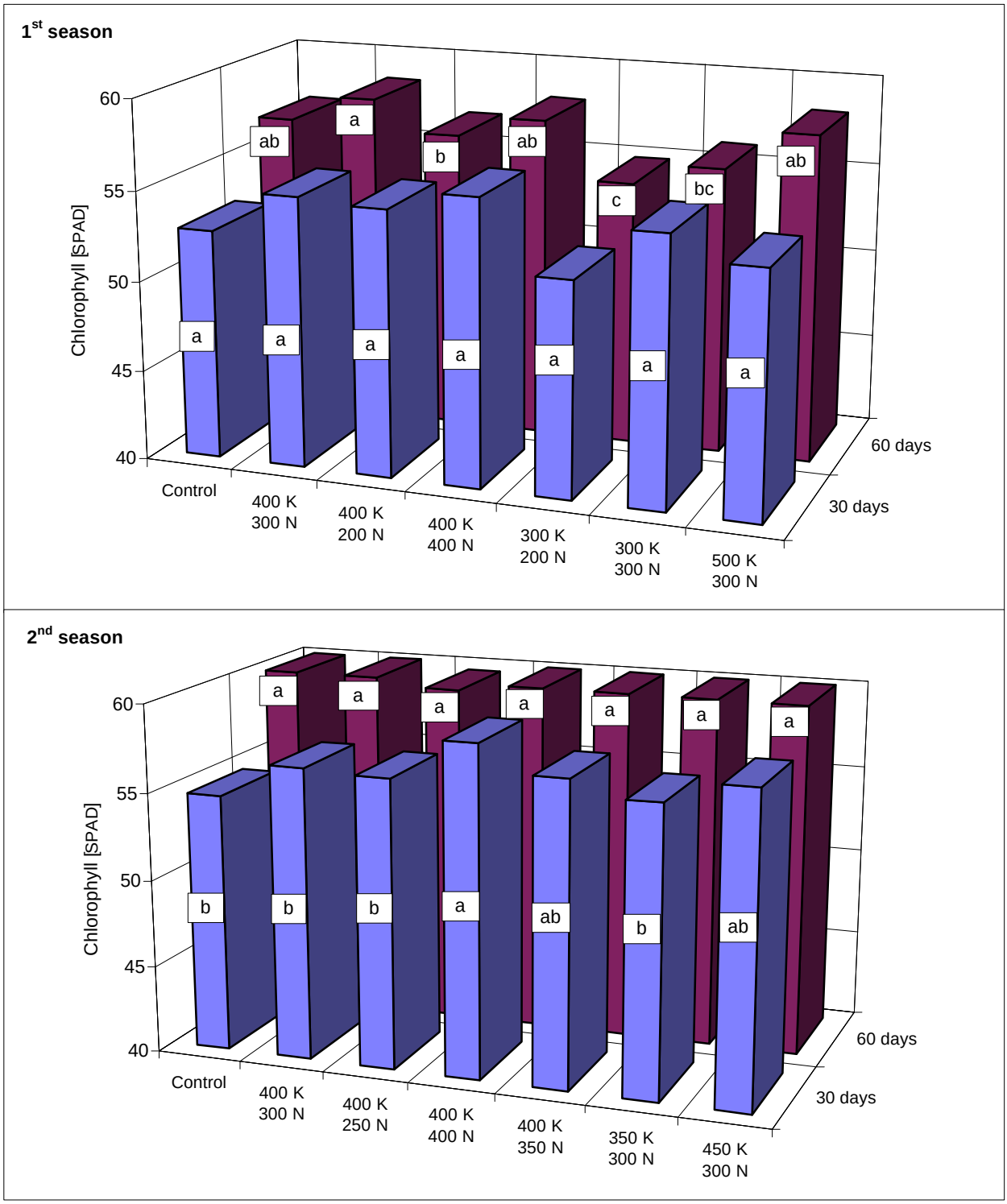
At 60 DAT, the area of 4th-youngest leaf was positively affected by N rate of 300 kg combined with 400 or 500 kg (1st season) or 450 kg (2nd season) of K_2O ha^{-1}. Control treatment resulted in the lowest leaf area 60 DAT in both seasons. No significant differences were detected between control treatment and combined application of 200 kg N with 300 or 400 kg K_2O ha^{-1} (1st season) and N at 250, 300 or 400 combined with K_2O at 400, 350 or 400 kg ha^{-1}, respectively (2nd season).

Application rates of N at 300 kg (60 DAT in the 1st season) or 400 kg (30 DAT in the 2nd season) combined with 400 kg K_2O ha^{-1} (in both seasons) resulted in the highest leaf chlorophyll content (Figure 4.8). The lowest content was obtained by application of N at 200 kg with K_2O at 300 kg ha^{-1} in the 1st season and by control treatment in the 2nd one. However, the same lowest trend was found (30 DAT in the 2nd season) by rates of N at 300, 250 or 300 combined with K_2O at 400, 400 or 350 kg ha^{-1}, respectively, without statistical differences compared to control.

Table 4.6 Effect of different levels of N and K (K_2O) supply on vegetative growth characters of artichoke plants 30 and 60 days after transplanting during the growing seasons 2000 and 2001 in Freising

Treatments kg ha^{-1} of N + K_2O	Plant height [**cm**]	No. of leaves/plant	Fresh weight of 4^{th}-leaf [**g**]	Dry weight of 4^{th}-leaf [**g**]	Area of 4^{th}-leaf [$\mathbf{cm^2}$]
1^{st} season					
	30 days after transplanting				
Control	33.7 b	8.42 a	40.2 b	5.41 a	202.8 a
300 + 400	36.1 a	8.83 a	40.7 a	5.59 a	209.3 a
200 + 400	35.0 b	8.58 a	38.6 b	5.23 a	196.3 a
400 + 400	37.4 a	8.92 a	42.3 a	5.56 a	211.7 a
200 + 300	34.7 b	8.33 a	39.7 b	5.44 a	203.9 a
300 + 300	36.3 a	8.58 a	41.5 a	5.83 a	218.6 a
300 + 500	37.0 a	8.92 a	39.6 b	5.53 a	207.3 a
	60 days after transplanting				
Control	65.0 ab	12.00 a	55.4 a	8.32 b	367.1 b
300 + 400	68.3 a	12.58 a	58.8 a	9.26 a	408.3 a
200 + 400	64.7 b	12.17 a	54.7 a	8.18 b	362.0 b
400 + 400	68.0 a	12.25 a	58.4 a	8.55 ab	377.1 ab
200 + 300	62.3 b	11.75 a	52.6 a	7.83 b	345.1 b
300 + 300	64.0 b	11.83 a	54.9 a	8.58 ab	378.4 ab
300 + 500	66.7 a	12.00 a	57.5 a	8.97 a	395.6 a
2^{nd} season					
	30 days after transplanting				
Control	35.5 b	8.07 a	37.9 b	4.86 b	208.5 a
300 + 400	37.9 ab	8.13 a	41.8 ab	5.42 a	235.3 a
250 + 400	36.7 b	7.87 a	39.5 b	4.97 b	215.0 a
400 + 400	39.1 a	8.13 a	42.3 a	5.42 a	231.8 a
350 + 400	37.5 ab	8.27 a	41.5 ab	5.43 a	243.1 a
300 + 350	36.8 b	8.00 a	40.8 ab	5.22 ab	229.9 a
300 + 450	38.3 ab	8.20 a	41.4 ab	5.41 a	234.1 a
	60 days after transplanting				
Control	65.9 c	11.1 c	55.7 b	8.37 b	383.2 b
300 + 400	71.7 ab	12.7 a	60.4 a	9.14 a	402.0 ab
250 + 400	66.8 c	10.9 c	55.6 b	8.43 b	390.1 b
400 + 400	69.9 b	11.9 b	57.1 b	8.54 b	383.5 b
350 + 400	71.3 ab	12.4 ab	59.3 ab	9.02 ab	394.6 ab
300 + 350	70.5 b	12.0 b	57.4 b	8.66 b	382.6 b
300 + 450	72.6 a	12.5 a	60.1 ab	9.21 a	405.2 a

Means within each column and sampling date followed by the same letter are not significantly different at $P<5\%$



Means of the same date with the same letter are not significantly different at $P<5\%$

Figure 4.8 Effect of different levels of N and K (K_2O) supply on leaf chlorophyll content (SPAD) of artichoke plants 30 and 60 days after transplanting during the growing seasons 2000 and 2001 in Freising

4.2.2 Bud yield

The early yield of buds as kg per plant and calculated in t per ha was highest with application of N at 300 kg (in both seasons) combined with 500 kg (in the 1st season) or 450 kg (in the 2nd season) of K_2O ha^{-1}, without significant differences between those rates of K_2O and rate of 400 kg K_2O ha^{-1} (Table 4.7).

Concerning the total yield, it is striking that dynamic application rates of N at 300 kg with K at 400 kg K_2O ha^{-1} insistently resulted in the highest bud yield (Table 4.7) and total number of buds per plant (Figure 4.9) compared to all fertigation treatments in both seasons. However, the differences between this treatment and combined rates of N at 350 or 300 kg with K_2O at 400 or 450 kg ha^{-1}, respectively, were not significant.

On the other hand, the lowest values of both early and total yield as well as total number of buds per plant were produced by application of 200 kg N combined with 300 Kg K_2O ha^{-1} in the 1st season and of N at 250 kg with K_2O at 400 Kg ha^{-1} in the 2nd season. Also, the same lower of early yield in the 2nd season was obtained with the treatment of control, 400 kg ha^{-1} of each N and K_2O or combined rates of N at 300 kg with K_2O at 350 Kg ha^{-1}, without any significant differences among all.

4.2.3 Bud traits

Different proportions of N and K did not affect the weight of main and secondary buds (Table 4.8) and the weight of the edible part (Figure 4.10). With exception, the treatment by 300 or 350 kg N with 400 kg K_2O ha^{-1} positively influenced the weight of secondary buds in the 2nd season, while the lowest weight was obtained by application of N at 250 kg with K_2O at 400 kg ha^{-1}. Also, application of 300 kg N with 400 or 500 kg K_2O ha^{-1} positively affected the weight of the edible part of secondary buds in the 1st season, without significant differences compared to control treatment. While, the treatment with 200 kg N combined with 300 or 400 kg K_2O ha^{-1} produced the lowest weight of the edible part (Figure 4.10).

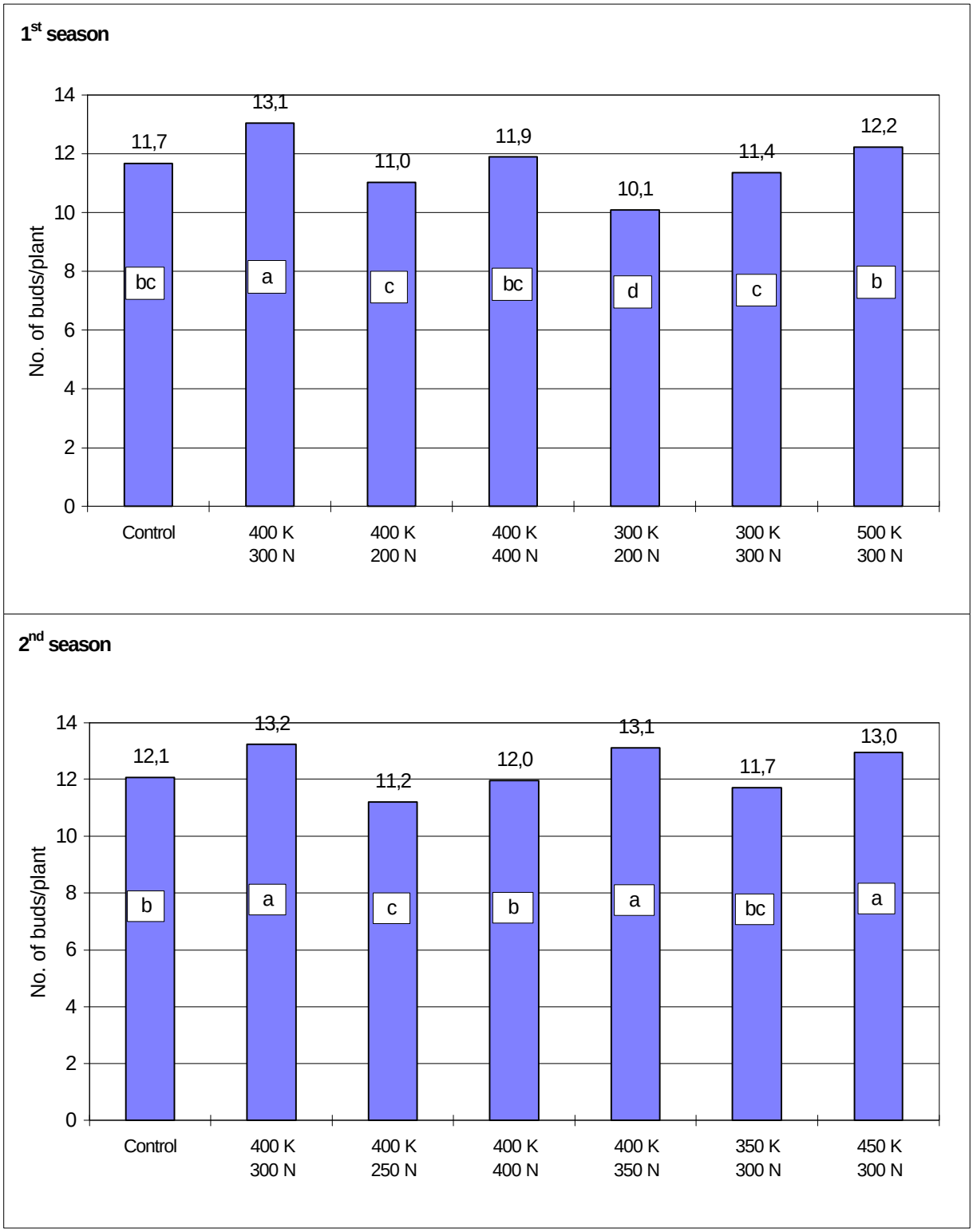
Length and diameter of buds were slightly affected by fertigation treatments. Application of N at 300 kg with K_2O at 500 kg ha^{-1} showed the highest length of main buds and application of N at 300 kg with K_2O at 400 kg ha^{-1} resulted in the highest length and diameter of secondary buds in the 1st season. The lowest length and diameter values of buds were obtained by application of 200 kg N with 300 kg K_2O ha^{-1}, without significant

differences in length of main buds comparing with application of 300 kg ha^{-1} of each N and K_2O or of 200 kg N with 400 kg K_2O ha^{-1} (Table 4.8).

Table 4.7 Effect of different levels of N and K (K_2O) supply on bud yield of artichoke during the growing seasons 2000 and 2001 in Freising

Treatments kg ha^{-1} of N + K_2O	Early yield		Total yield	
	[kg/plant]	[t/ha]	[kg/plant]	[t/ha]
1st season				
Control	0.45 b	5.00 b	1.63 c	18.06 c
300 + 400	0.56 a	6.22 a	1.88 a	20.93 a
200 + 400	0.43 b	4.81 b	1.51 d	16.75 d
400 + 400	0.44 b	4.93 b	1.62 c	18.04 c
200 + 300	0.35 c	3.94 c	1.35 e	14.95 e
300 + 300	0.47 b	5.24 b	1.60 c	17.81 c
300 + 500	0.59 a	6.52 a	1.76 b	19.60 b
2nd season				
Control	0.54 b	5.97 b	1.76 b	19.52 b
300 + 400	0.61 a	6.76 a	1.99 a	22.10 a
250 + 400	0.50 b	5.53 b	1.60 c	17.73 c
400 + 400	0.50 b	5.58 b	1.76 b	19.56 b
350 + 400	0.58 ab	6.49 ab	1.98 a	22.01 a
300 + 350	0.53 b	5.88 b	1.71 b	19.00 b
300 + 450	0.62 a	6.93 a	1.95 a	21.70 a

Means within each column and season followed by the same letter are not significantly different at $P<5\%$



Means with the same letter are not significantly different at $P<5\%$

Figure 4.9 Effect of different levels of N and K (K_2O) supply on total number of artichoke buds per plant during the growing seasons 2000 and 2001 in Freising

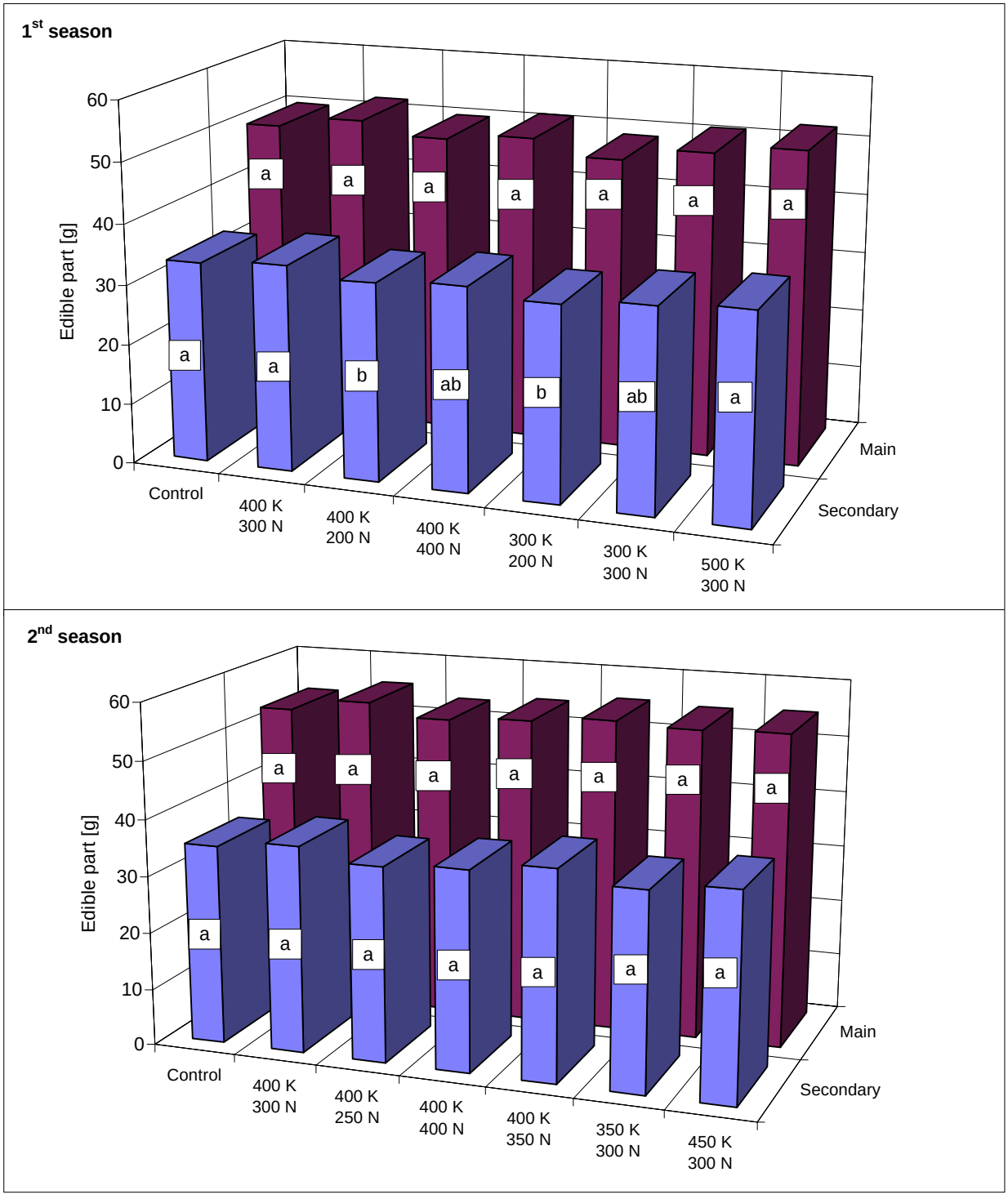
Table 4.8 Effect of different levels of N and K (K_2O) supply on the traits of main and secondary buds of artichoke during the growing seasons 2000 and 2001 in Freising

Treatments kg ha^{-1} of N + K_2O	Main bud			Secondary bud		
	Weight [**g**]	Length [**mm**]	Diameter [**mm**]	Weight [**g**]	Length [**mm**]	Diameter [**mm**]
1st season						
Control	252.6 a	100.2 ab	82.7 a	161.3 a	84.2 b	75.2 bc
300 + 400	255.9 a	101.9 ab	87.0 a	166.0 a	87.4 a	78.5 a
200 + 400	254.3 a	99.7 b	84.3 a	159.3 a	82.8 bc	74.1 bc
400 + 400	253.1 a	100.8 ab	83.6 a	162.7 a	85.3 ab	76.1 b
200 + 300	248.8 a	98.4 b	80.3 a	158.2 a	81.4 c	73.5 c
300 + 300	251.4 a	99.8 b	82.7 a	162.3 a	84.5 b	75.3 bc
300 + 500	256.5 a	102.5 a	86.9 a	165.3 a	86.7 ab	78.1 ab
2nd season						
Control	258.0 a	101.8 a	84.2 e	165.2 b	84.9 ab	75.3 a
300 + 400	262.2 a	102.9 a	88.6 ab	170.2 a	85.2 a	76.8 a
250 + 400	256.0 a	101.8 a	86.0 cd	162.4 c	82.7 c	74.8 a
400 + 400	258.7 a	102.0 a	86.5 c	166.3 b	84.1 b	76.0 a
350 + 400	263.2 a	103.6 a	89.6 a	171.0 a	85.5 a	77.4 a
300 + 350	257.2 a	102.5 a	85.3 d	163.9 b	84.0 b	75.4 a
300 + 450	261.7 a	102.9 a	88.0 b	169.1 ab	85.2 a	77.6 a

Means within each column and season followed by the same letter are not significantly different at $P<5\%$

In the 2nd season, the treatment of 350 kg N with 400 kg K_2O ha^{-1} positively influenced diameter of main buds and length of secondary buds, without significant differences in length of secondary buds comparing with application of 300 kg N with 400 or 450 kg K_2O ha^{-1} (Table 4.8). Conversely, the control treatment produced the lowest diameter of main

buds, and the application of 250 kg N with 400 kg K_2O ha^{-1} resulted in the lowest length of secondary buds (Table 4.8).



Means with the same letter are not significantly different at $P<5\%$

Figure 4.10 Effect of different levels of N and K (K_2O) supply on the weight of edible part of main and secondary buds of artichoke during the growing seasons 2000 and 2001 in Freising

4.2.4 Chemical composition

The content of total nitrogen in the 4th-youngest leaf 60 DAT was affected by fertigation treatments in the 1st season only. The combined application of both N and K_2O at 300 or 400 kg ha^{-1} of each showed the highest content, while the lowest N was obtained by application of N at 200 kg with K_2O at 400 kg ha^{-1} (Table 4.9).

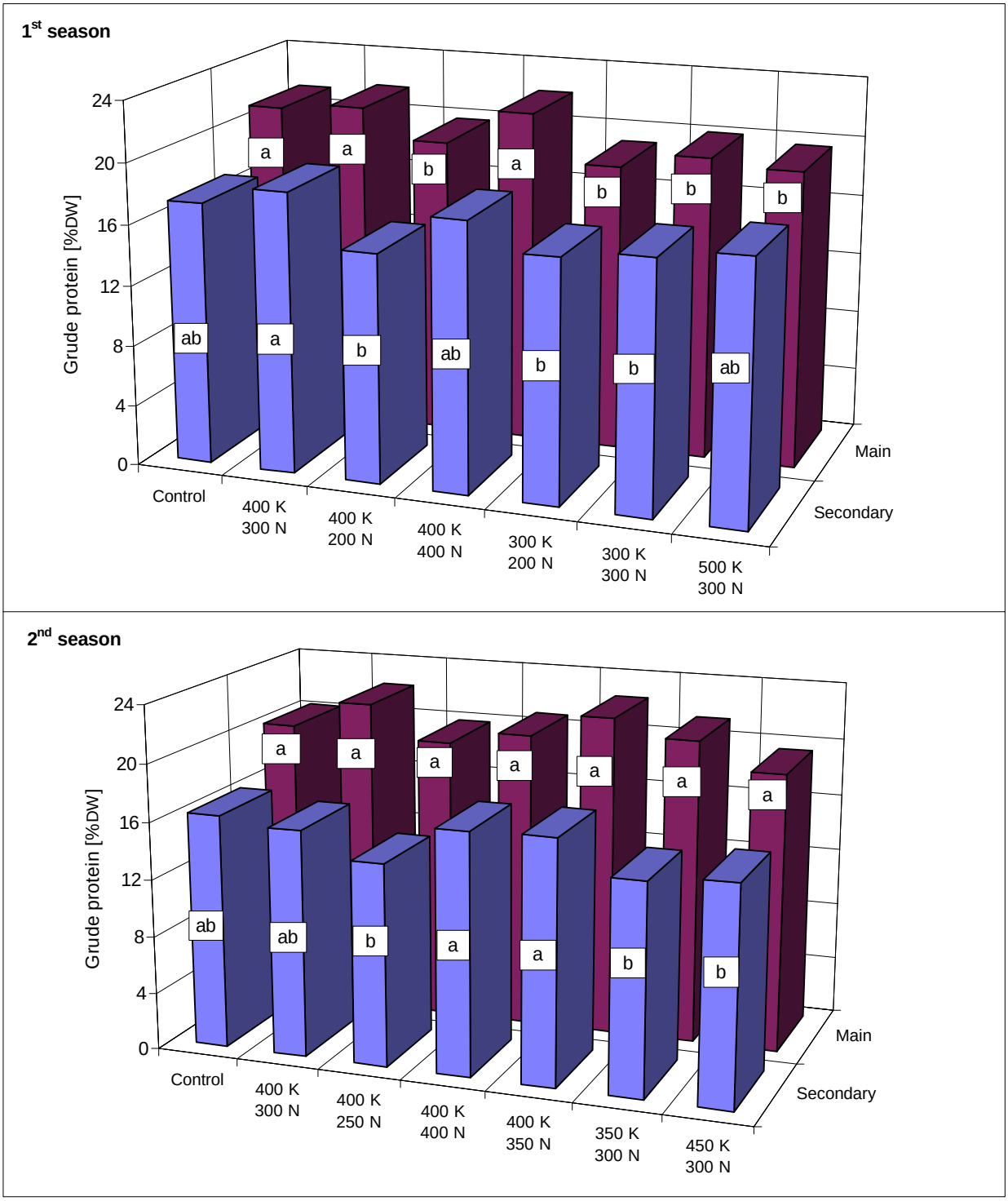
Concerning the content of N and crude protein in the edible part, the presented data in Table 4.9 and Figure 4.11 reveal that the highest content in the main and secondary buds was obtained by combined application of 300 kg N and 400 kg K_2O ha^{-1} in the 1st season, without significant differences in main buds compared to control treatment or combined rates of 400 kg ha^{-1} of each N and K_2O. Also, application rates of 350 or 400 kg N with 400 kg K_2O ha^{-1} achieved the same trend of highest N content and crude protein in secondary buds in the 2nd season. Conversely, the lowest content of N and crude protein in main and secondary buds was obtained by the treatment with the lowest rate of N (200 kg) with 300 or 400 kg K_2O ha^{-1} or combined rates of both N and K_2O at 300 kg ha^{-1} of each, without significant differences in main buds compared to application rates of N at 300 kg combined with 500 kg K_2O ha^{-1} in the 1st season. In the 2nd one, the same lowest trend was found in secondary buds by the treatment with 250 kg N with 400 kg K_2O ha^{-1}, without significant differences compared to application rates of N at 300 kg combined with 350 or 450 kg K_2O ha^{-1}.

Generally, chemical analysis of leaves and edible parts indicated that the content of both P and K remained unchanged for all fertigation treatments (Table 4.9). With the exception that content of K in the edible part of secondary buds in the 1st season was positively affected by combined application of both N and K at 400 kg ha^{-1}, and that the control treatment resulted in the lowest K content.

Table 4.9 Effect of different levels of N and K (K_2O) supply on contents of N, P and K in 4th-leaf and edible part of main and secondary buds of artichoke during the growing seasons 2000 and 2001 in Freising

Treatments kg ha^{-1} of N + K_2O	4th-leaf			Edible part		
	N [% DW]	P [% DW]	K [% DW]	N [% DW]	P [% DW]	K [% DW]
1st season						
	30 days after transplanting			Main buds		
Control	4.37 a	0.26 a	4.03 a	3.40 a	0.32 a	3.94 a
300 + 400	4.59 a	0.32 a	4.04 a	3.46 a	0.41 a	4.02 a
200 + 400	4.31 a	0.31 a	3.94 a	3.15 b	0.39 a	4.01 a
400 + 400	4.66 a	0.32 a	4.03 a	3.52 a	0.34 a	3.71 a
200 + 300	4.42 a	0.40 a	4.25 a	3.04 b	0.34 a	3.74 a
300 + 300	4.51 a	0.41 a	4.27 a	3.20 b	0.29 a	3.52 a
300 + 500	4.28 a	0.36 a	4.31 a	3.13 b	0.32 a	3.76 a
	60 days after transplanting			Secondary buds		
Control	4.26 ab	0.29 a	4.02 a	2.77 ab	0.31 a	3.34 d
300 + 400	4.05 bc	0.32 a	3.93 a	2.96 a	0.37 a	3.89 b
200 + 400	3.88 c	0.33 a	4.20 a	2.41 b	0.37 a	3.87 b
400 + 400	4.34 a	0.32 a	4.05 a	2.84 ab	0.41 a	4.01 a
200 + 300	3.94 c	0.37 a	4.09 a	2.55 b	0.40 a	3.77 b
300 + 300	4.10 a	0.36 a	4.14 a	2.63 b	0.43 a	3.64 c
300 + 500	4.12 b	0.38 a	4.08 a	2.73 ab	0.42 a	3.94 ab
2nd season						
	30 days after transplanting			Main buds		
Control	4.14 a	0.44 a	4.03 a	3.24 a	0.45 a	3.57 a
300 + 400	4.41 a	0.42 a	4.16 a	3.55 a	0.42 a	3.34 a
250 + 400	4.29 a	0.44 a	4.12 a	3.17 a	0.35 a	3.53 a
400 + 400	4.60 a	0.43 a	4.41 a	3.32 a	0.32 a	3.33 a
350 + 400	4.53 a	0.44 a	4.21 a	3.58 a	0.35 a	3.35 a
300 + 350	4.45 a	0.35 a	4.34 a	3.40 a	0.40 a	3.28 a
300 + 450	4.36 a	0.30 a	4.24 a	3.11 a	0.39 a	3.17 a
	60 days after transplanting			Secondary buds		
Control	4.21 a	0.36 a	3.62 a	2.62 ab	0.34 a	3.15 a
300 + 400	4.42 a	0.35 a	3.81 a	2.54 ab	0.37 a	3.15 a
250 + 400	4.35 a	0.35 a	3.70 a	2.26 b	0.36 a	3.36 a
400 + 400	4.48 a	0.41 a	4.04 a	2.69 a	0.37 a	3.22 a
350 + 400	4.23 a	0.44 a	3.92 a	2.71 a	0.43 a	3.32 a
300 + 350	4.20 a	0.40 a	4.00 a	2.35 b	0.37 a	3.31 a
300 + 450	4.14 a	0.36 a	4.74 a	2.42 b	0.41 a	3.32 a

Means within each column and sampling date followed by the same letter are not significantly different at $P<5\%$



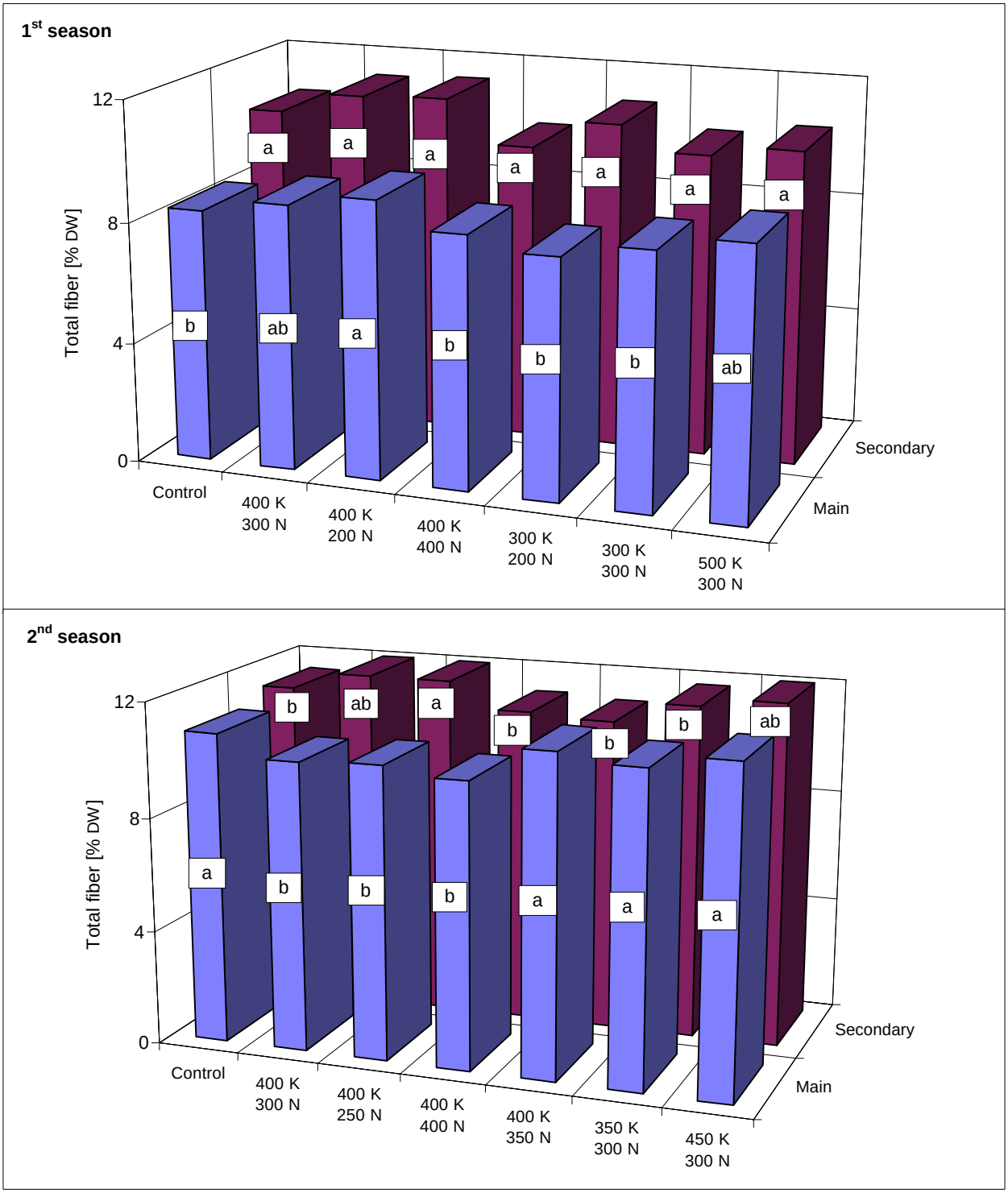
Means with the same letter are not significantly different at $P<5\%$

Figure 4.11 Effect of different levels of N and K (K_2O) supply on crude protein content in the edible part of main and secondary buds of artichoke during the growing seasons 2000 and 2001 in Freising

The effect of the different fertigation treatments on the content of total fiber in the edible part of main and secondary buds is exhibited in Figure 4.12. The obtained results show that application of N at 200 kg with K_2O at 400 kg ha^{-1} resulted in the highest total fiber content in the edible part of the main buds in the 1st season. The opposite trend was found with treatments of 200, 300 or 400 kg N combined with 300, 300 or 400 kg K_2O ha^{-1}, respectively, without significant differences compared to control treatment. In the 2nd season, the highest content of total fiber in the edible part of main buds was obtained by application of 300 kg N with 450 kg K_2O ha^{-1}, without significant differences compared to control treatment or combined rates of N at 300 or 350 with K_2O at 350 or 400 kg ha^{-1}, respectively. The same highest trend of total fiber in the edible part of secondary buds occurred by N at 250 kg with K_2O at 400 kg ha^{-1}. In contrary, the treatment with 400 kg ha^{-1} of both N and K_2O resulted in the lowest content of total fiber in the edible part of main and secondary buds. However, no significant differences were obtained between this treatment and combined rates of 250 or 300 kg N with 400 kg K_2O ha^{-1} on total fiber content of edible part (main buds), and control treatment or combined rates of N at 300 or 350 with K_2O at 350 or 400 kg ha^{-1}, respectively (secondary buds).

With regard to the response of soil content of nitrate and available potassium in the 2nd season, the obtained results did not show any significant differences among all fertigation proportions of both N and K_2O rates.

Generally and irrespective of fertigation treatments, both nitrate and available K increased slightly in both layers of 0-30 cm and 30-60 cm of soil from 30 to 45 DAT, and gradually decreased during the following growing period (Figure 4.13).



Means with the same letter are not significantly different at $P<5\%$

Figure 4.12 Effect of different levels of N and K (K_2O) supply on total fiber content in the edible part of main and secondary buds of artichoke during the growing seasons 2000 and 2001 in Freising

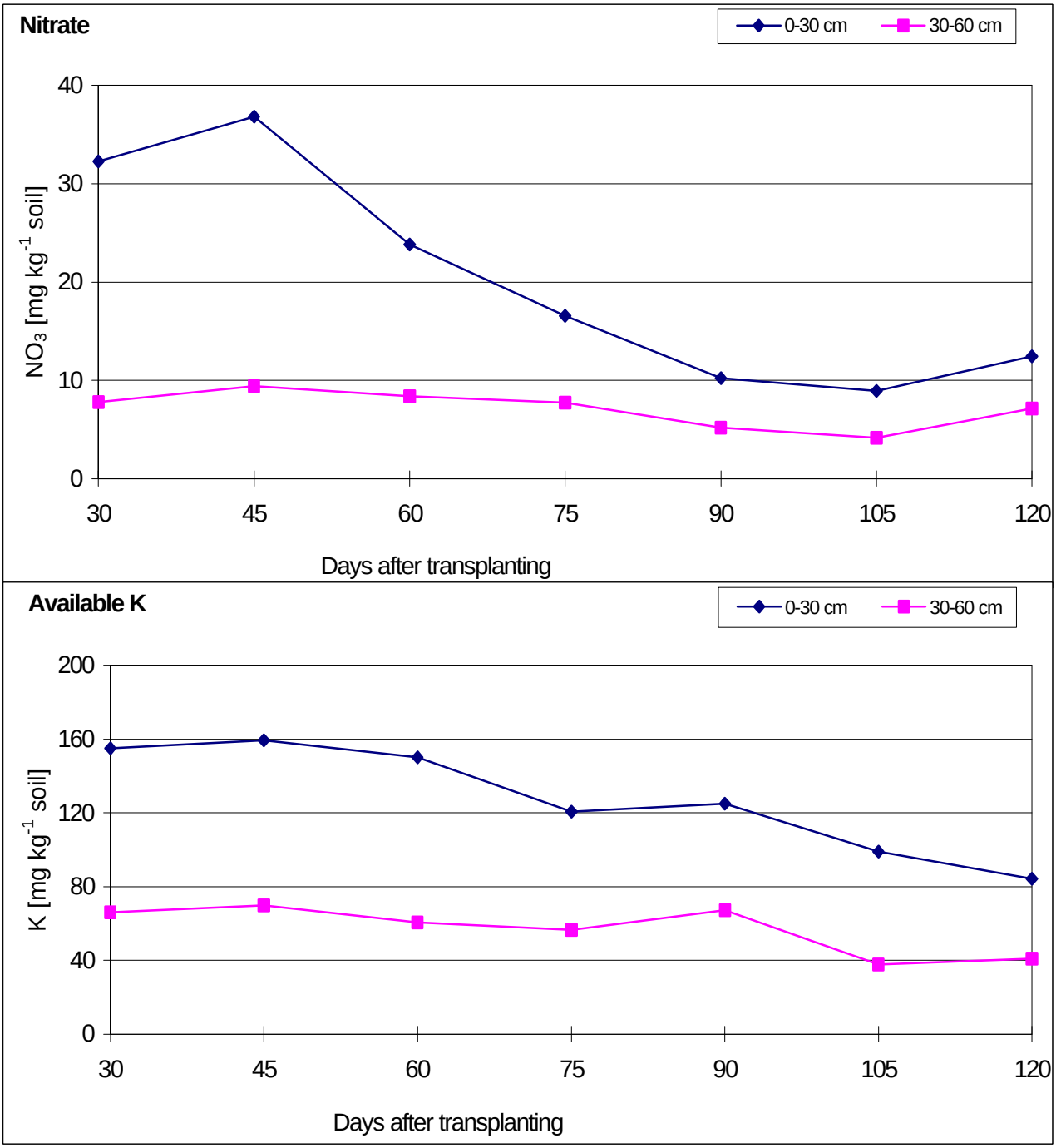


Figure 4.13 Nitrate and available potassium contents at two depths of artichoke soil during growing season of 2001 in Freising

4.3 Salinity experiments

4.3.1 Salt tolerance of seedlings (Experiment A)

4.3.1.1 Vegetative growth characters

The effect of NaCl applied to the nutrient solution on vegetative growth of artichoke seedling is presented in Table 4.10. All vegetative growth characters such as height of plant, number of leaves, total leaf area and dry weight of shoots as well as dry weight of roots per plant sharply decreased by increasing NaCl concentration in the nutrient solution from 0 to 150 mmol l^{-1}. The reduction in dry weight of total biomass was 21, 65 and 83% by application of NaCl to the nutrient solution at 50, 100 and 150 mmol l^{-1}, respectively compared to untreated control.

Table 4.10 Effect of different salinity levels on vegetative growth characters of artichoke seedlings 30 days after treatments start

Treatments of NaCl	Plant height [**cm**]	No. of leaves/plant	Total leaf area [**cm^2**]	Shoots dry weight [**g**]	Roots dry weight [**g**]
0 mmol l^{-1}	33.3 a	7.4 a	690.2 a	5.75 a	1.52 a
50 mmol l^{-1}	26.4 b	6.7 b	274.9 b	4.69 a	1.05 b
100 mmol l^{-1}	19.2 c	6.1 b	225.0 b	2.11 b	0.46 c
150 mmol l^{-1}	12.2 d	5.3 c	91.8 c	0.98 c	0.23 c

Means within each column followed by the same letter are not significantly different at $P<5\%$

4.3.1.2 Chemical Composition

The response of electrical conductivity (EC) of the soil and soil nutrient content to different salinity rates was sharp (Table 4.11). The content of Cl and Na in the soil as well as soil EC gradually increased with increasing NaCl concentration in the nutrient solution.

On the other hand, K content of soil did not show a consistent trend. However, K slightly tended to decrease by application of 50 mmol l^{-1} NaCl to the nutrient solution, then increased to the highest content and decreased to the lowest content of K with concentration of NaCl at 100 and 150 mmol l^{-1}, respectively.

No significant differences among all salinity treatments were detected concerning the Ca content of the soil.

Table 4.11 Effect of different salinity levels on nutrient content (mg kg^{-1}) and EC (dS m^{-1}) of seedlings soil 30 days after treatments start

Treatments of NaCl	Cl [**mg kg^{-1}**]	Na [**mg kg^{-1}**]	K [**mg kg^{-1}**]	Ca [**mg kg^{-1}**]	EC of 1:10 solution [**dS m^{-1}**]
0 mmol l^{-1}	232 d	371 d	88 ab	125 a	0.28 d
50 mmol l^{-1}	1121 c	915 c	82 b	118 a	0.50 c
100 mmol l^{-1}	2057 b	1749 b	100 a	116 a	0.85 b
150 mmol l^{-1}	2583 a	2095 a	60 c	118 a	1.06 a

Means within each column followed by the same letter are not significantly different at $P<5\%$

Figure 4.14 reveals the nutrient content of shoots and roots of artichoke seedlings in response to the salinity levels of the nutrient solution.

The obtained results show that the content of Cl and Na sharply increased in both shoots and roots with increasing application of NaCl to the nutrient solution.

The same trend for K content of the roots up to at 100 mmol l^{-1} NaCl was found, but tended to be lower at the highest rate of salinity. Meanwhile, the content of both K and Ca in the shoots was adversely affected with increasing salinity levels. Concerning Mg content in shoots, it significantly decreased when NaCl was added at 50 mmol l^{-1} to the nutrient solution compared to the control treatment, and was remaining almost constant with further increase of salinity levels.

Moreover, the content of both Ca and Mg in the root tissues remained unchanged by all salinity treatments.

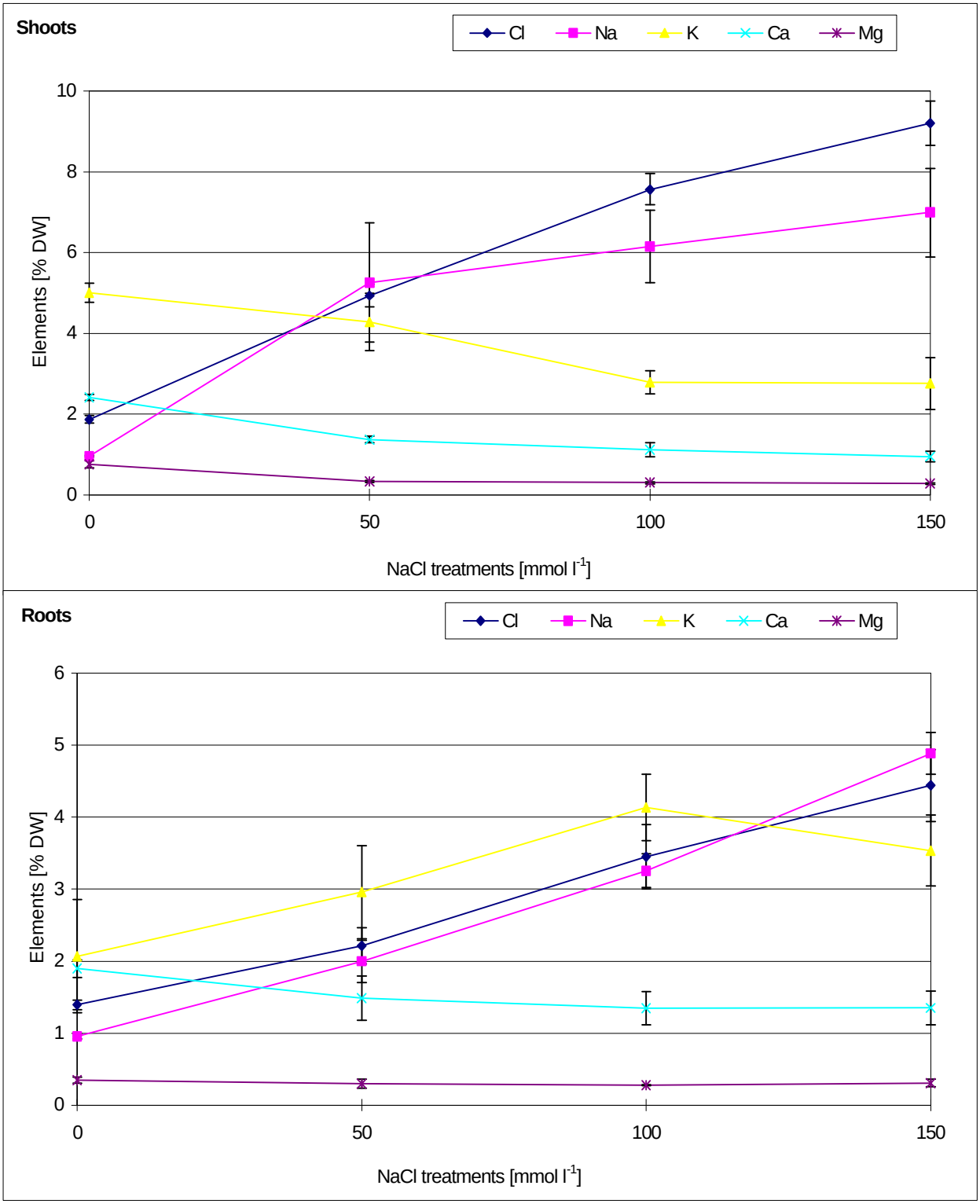


Figure 4.14 Effect of different salinity levels on nutrient contents in artichoke seedling shoots and roots (% DW) 30 days after treatments start

4.3.2 Promotion of salt tolerance (Experiment B)

4.3.2.1 Vegetative growth and physiological characters

The application of 50 mmol l^{-1} NaCl to the nutrient solution resulted in a saline solution with a final EC at 6.5 dS m^{-1}. Vegetative growth of artichoke plants represented by plant height, number of leaves per plant and area of the 4th-youngest leaf was depressed by the salinity treatment compared to the non-saline control 15 days (Table 4.12), 30 days (Table 4.13) and 45 days (Table 4.14) after treatments start. In the same way, the salinity treatment showed a negative effect on dry weight of the 4th-youngest leaf at all measurement times (Figure 4.15). Moreover, the same trend was obtained for physiological parameters such as net photosynthesis rate and stomatal conductance at all measurement times and transpiration 45 days after treatments start.

Table 4.12 Effect of nutrient and *Bacillus subtilis* additive on vegetative growth and physiological characters of salt-stressed artichoke plants compared to the non-saline control 15 days after treatments start

Treatments	Plant height [**cm**]	No. of leaves/ plant	4th-leaf area [**cm^2**]	Photosynthesis [**µmol m^{-2} s^{-1}**]	Transpiration [**mol m^{-2} s^{-1}**]	Stomatal conductance [**mol m^{-2} s^{-1}**]
Factor A:						
No salinity	81.3 a	11.3 a	569.6 a	13.0 a	6.2 a	0.74 a
Salinity only	69.0 d	9.8 d	377.0 c	6.0 d	5.8 a	0.42 b
Salinity + Ca	71.4 c	10.2 c	403.6 c	9.0 c	6.2 a	0.48 b
Salinity + Bacillus	74.8 b	10.8 b	477.0 b	11.3 b	5.9 a	0.59 ab
Factor B:						
Foliar Fe-Mn-Zn	75.7 a	10.9 a	475.9 a	9.5 a	6.0 a	0.57 a
No foliar Fe-Mn-Zn	72.5 b	10.2 b	437.7 b	10.1 a	6.0 a	0.54 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Inoculation of salt-stressed plants with *Bacillus subtilis* or addition of supplemental Ca to the saline nutrient solution decreased the adverse effect of salinity on vegetative growth characters and improved gas exchange. *Bacillus subtilis* ranked the first, followed by supplemental Ca for improving plant height, area and dry weight of the 4th-youngest leaf at

all measurement times, net photosynthesis rate 15 and 45 days after treatments start as well as number of leaves per plant and stomatal conductance 15 days after treatments start. Improvement compared to the saline control, but no significant differences between both additives were detected concerning their effect on number of leaves per plant 30 and 45 days and stomatal conductance 45 days after treatments start. No positive response for net photosynthesis rate and stomatal conductance of salt-stressed plants was obtained by application of neither *Bacillus subtilis* nor additional Ca compared to the saline control without further additives 30 days after treatments start. On the other hand, transpiration was not influenced by any treatment 15 and 30 days after treatments start.

Table 4.13 Effect of nutrient and *Bacillus subtilis* additive on vegetative growth and physiological characters of salt-stressed artichoke plants compared to the non-saline control 30 days after treatments start

Treatments	Plant height [**cm**]	No. of leaves/ plant	4th-leaf area [**cm^2**]	Photosynthesis [**µmol m^{-2} s^{-1}**]	Transpiration [**mol m^{-2} s^{-1}**]	Stomatal conductance [**mol m^{-2} s^{-1}**]
Factor A:						
No salinity	89.7 a	14.7 a	644.0 a	8.8 a	6.5 a	0.40 a
Salinity only	74.3 d	12.0 c	472.5 c	3.4 b	5.7 a	0.26 b
Salinity + Ca	78.6 c	13.1 b	511.3 bc	4.3 b	5.7 a	0.30 b
Salinity + Bacillus	82.7 b	13.4 b	559.5 b	5.6 b	5.8 a	0.30 b
Factor B:						
Foliar Fe-Mn-Zn	82.8 a	13.8 a	559.1 a	6.1 a	5.8 a	0.32 a
No foliar Fe-Mn-Zn	79.8 b	12.8 b	534.5 b	5.0 a	6.0 a	0.30 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

With regard to the effect of foliar application of mixture of micronutrients (Fe-Mn-Zn), the obtained results show superiority in all vegetative growth characters at all measurement times, except area and dry weight of the 4th-youngest leaf 45 days after treatments start compared to the unsprayed treatment. On the contrary, foliar application of mixture of Fe, Mn and Zn did not affect all physiological parameters at all measurement times. With the

exception that net photosynthesis rate 45 days after treatments start increased due to the micronutrient spraying.

Table 4.14 Effect of nutrient and *Bacillus subtilis* additive on vegetative growth and physiological characters of salt-stressed artichoke plants compared to the non-saline control 45 days after treatments start

Treatments	Plant height [**cm**]	No. of leaves/ plant	4th-leaf area [**cm²**]	Photosynthesis [**µmol m⁻² s⁻¹**]	Transpiration [**mol m⁻² s⁻¹**]	Stomatal conductance [**mol m⁻² s⁻¹**]
Factor A:						
No salinity	101.0 a	15.8 a	569.4 a	8.8 a	6.4 a	0.55 a
Salinity only	80.2 d	13.9 c	452.7 c	4.2 d	5.5 c	0.29 c
Salinity + Ca	85.2 c	14.7 b	460.7 c	5.8 c	5.8 b	0.36 b
Salinity + Bacillus	92.2 b	14.9 b	534.7 b	6.6 b	5.9 ab	0.40 b
Factor B:						
Foliar Fe-Mn-Zn	91.3 a	15.1 a	510.5 a	6.5 a	6.0 a	0.42 a
No foliar Fe-Mn-Zn	88.0 b	14.5 b	498.2 a	6.2 b	5.8 a	0.38 a

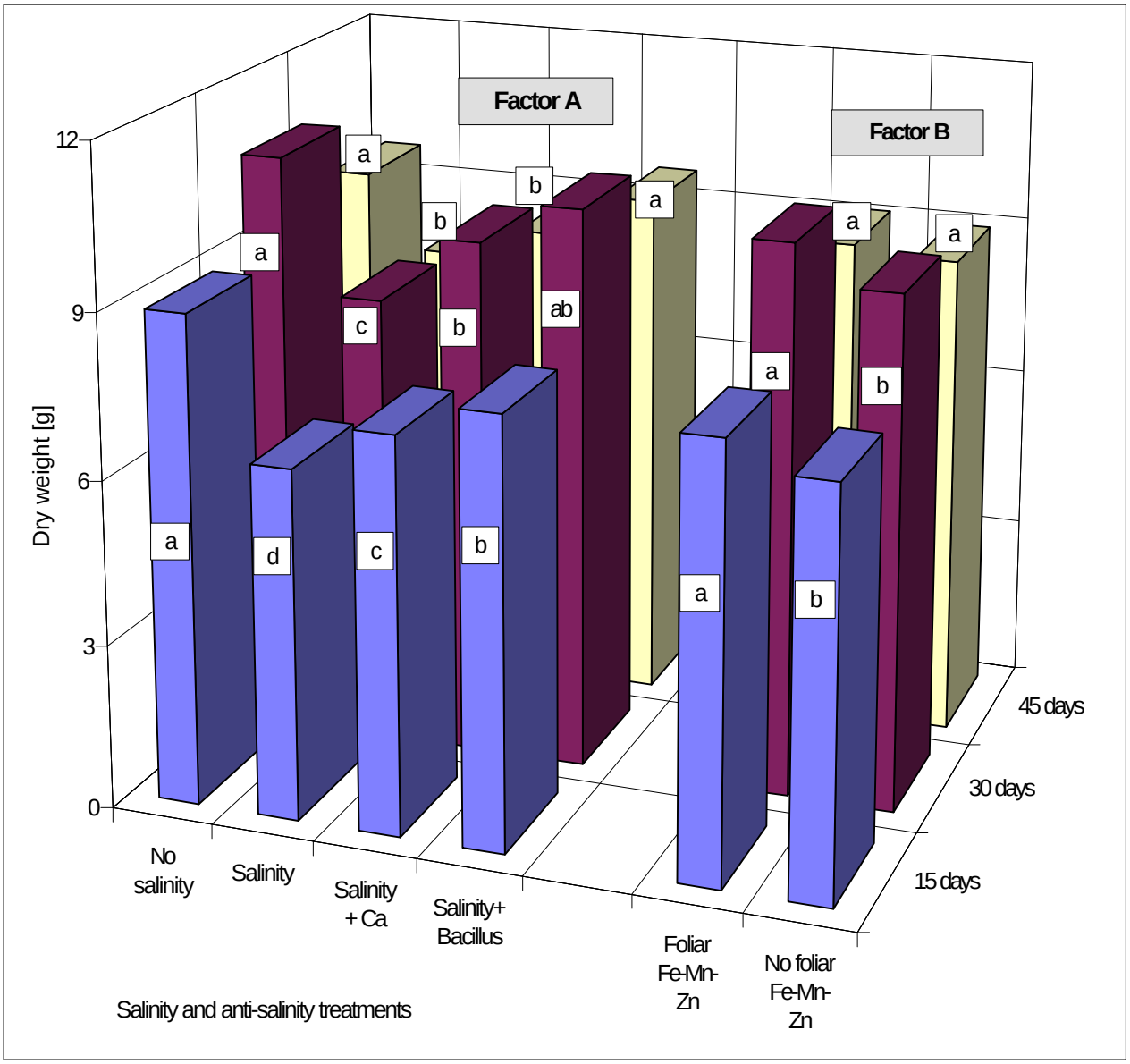
Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

At the end of the generative phase, 90 days after treatment start, the dry weight of total biomass of epigeal (shoots) and underground (roots) plant parts for each treatment is documented in Figure 4.16. Shoot dry weight per plant decreased by salinity treatment (6.5 dS m^{-1}) via application of NaCl into nutrient solution. Inoculation with *Bacillus subtilis* treatment proved a good effectiveness on shoot dry weight, but no positive effect was observed for additional Ca in the saline nutrient solution.

The foliar spraying of Fe-Mn-Zn enhanced shoot dry weight compared to unsprayed treatment. While dry weight of roots per plant did not show any significant differences among all treatments (Figure 4.16).

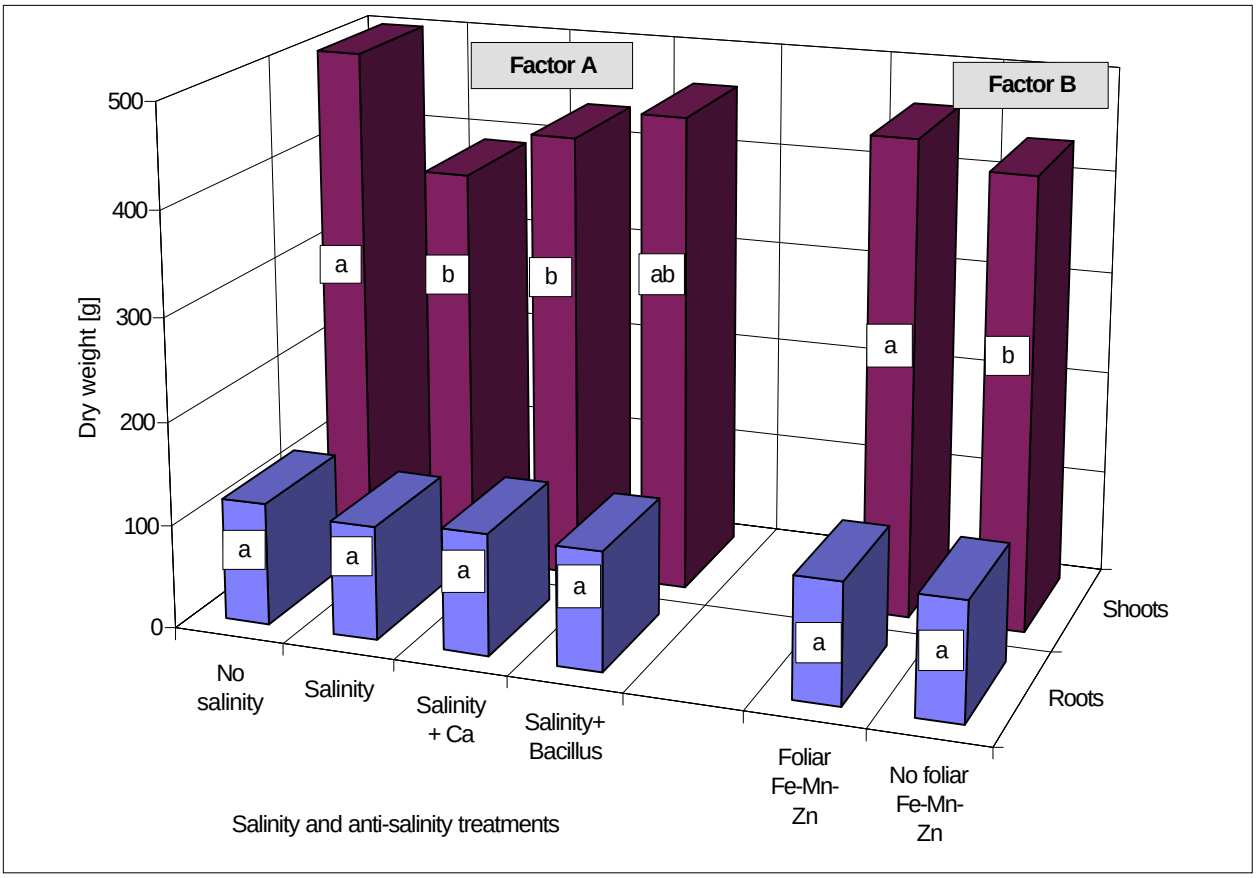
The obtained results indicate that the interaction treatments between EC of nutrient solution and additive of extra Ca or *Bacillus subtilis* (Factor A) and foliar application of micronutrients (Fe-Mn-Zn) compared to no spraying (Factor B) had generally no

significant effects on vegetative growth and physiological characters (Appendix 1 and 2). These results suggest that the two factors of the interaction act independently. However, the higher growth and physiological characters were obtained by non-saline treatment with or without foliar application of micronutrients (Fe-Mn-Zn) compared to the other interaction treatments.



Means within each factor and sampling date followed by the same letter are not significantly different at $P<5\%$

Figure 4.15 Effect of nutrient and *Bacillus subtilis* additive on the dry weight of the 4th-leaf of salt-stressed artichoke compared to the non-saline control 15, 30 and 45 days after treatments start

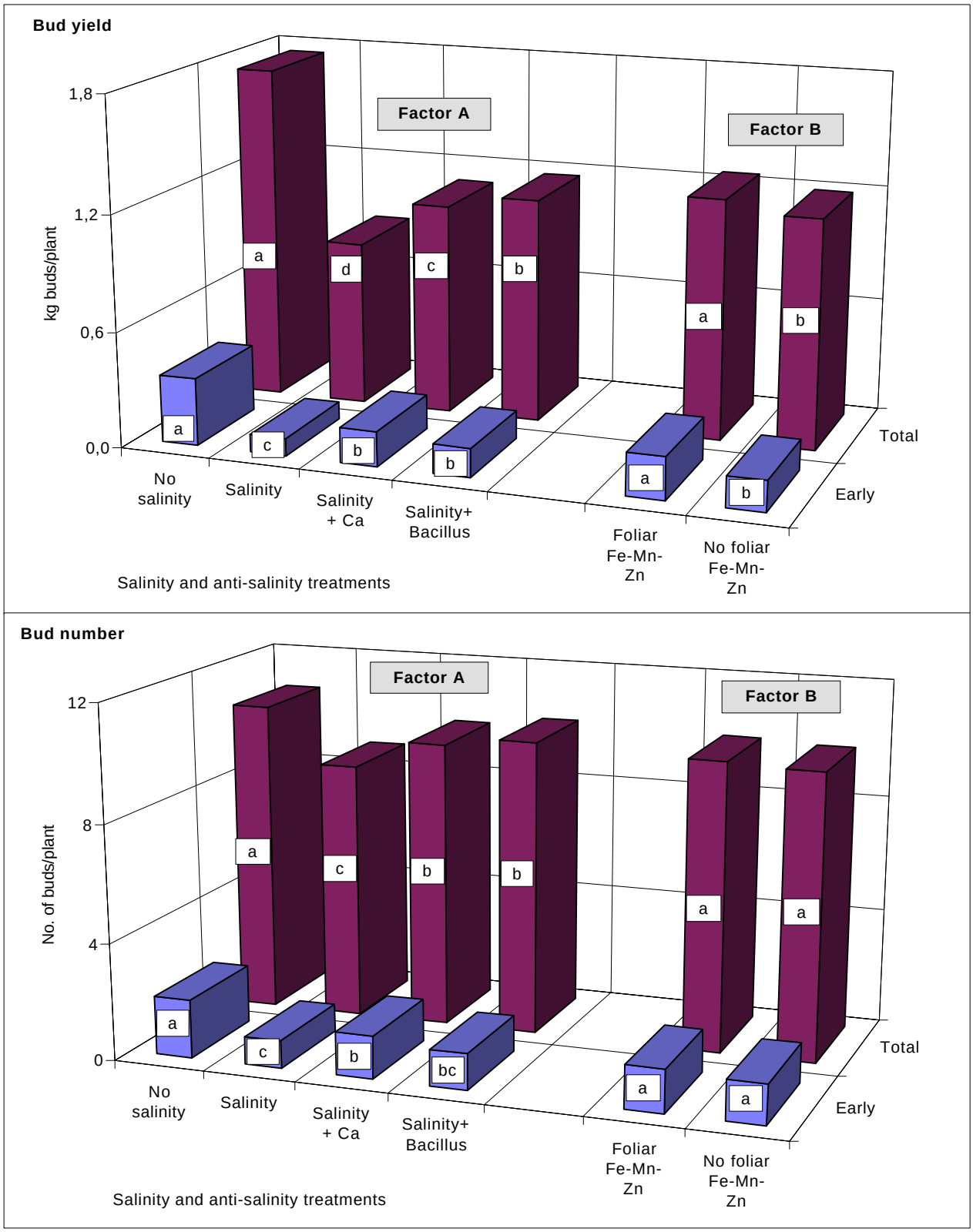


Means within each factor followed by the same letter are not significantly different at $P<5\%$

Figure 4.16 Effect of nutrient and *Bacillus subtilis* additive on total dry weight of shoots and roots per plant of salt-stressed artichoke compared to the non-saline control 90 days after treatments start

4.3.2.2 Bud yield

Salinity treatment (6.5 dS m^{-1}) reduced both early and total yield of buds as weight and number of buds per plant compared to the non-saline control treatment (Figure 4.17). Moreover, saline nutrient solution reduced the marketable yield of buds to 39% compared to non-saline control (Table 4.15). The additive of *Bacillus subtilis* or extra Ca enhanced early and total bud yield under salinity conditions. Total yield as weight per plant was higher with the treatment of *Bacillus subtilis.* On the other hand, early yield as number of buds per plant was higher with the treatment of additional Ca. No significant differences were noticed between the two additives in their effect on early yield as weight per plant as well as total yield as number of buds per plant. Inoculation of salt-stressed plants with *Bacillus subtilis* and additional Ca into saline nutrient solution increased the marketable yield to 152 and 140% compared to saline control without further additives (Table 4.15).



Means within each factor followed by the same letter are not significantly different at $P<5\%$

Figure 4.17 Effect of nutrient and *Bacillus subtilis* additive on weight and number of early and total bud yield per plant of salt-stressed artichoke compared to the non-saline control

Table 4.15 Economic value of nutrient and *Bacillus subtilis* additive on marketable yield of buds compared to no additives

Treatments	Marketable yield [**kg buds/plant**]	Compared to control [**%**]	Compared to salinity [**%**]
Factor A:			
No salinity	1.47 a	100	
Salinity only	0.57 d	39	100
Salinity + Ca	0.80 c	54	140
Salinity + Bacillus	0.87 b	59	152
Factor B:			
Foliar Fe-Mn-Zn	0.96 a	108	
No foliar Fe-Mn-Zn	0.89 b	100	

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Foliar application of micronutrients (Fe-Mn-Zn) improved the productivity (weight of buds), but did not affect the number of buds per plant of early and total yield compared to unsprayed treatment. The marketable yield of buds increased by foliar application to 108% compared to unsprayed treatment (Table 4.15).

No significant effects for the two studied factors were noticed on bud yield and its components (Appendix 2).

4.3.2.3 Water measurements

Although plants in all treatments were supplied by approximately the same amount of water, the drained water varied from one treatment to the other (Table 4.16) indicating the effect of the treatments on water consumption and water use efficiency (WUE). The lowest percent of drain water (57.7%) was in the control treatment compared to all the saline treatments with or without further additives of *Bacillus subtilis* or extra Ca (75.3-76.4%).

The calculated net consumption of water per plant decreased in the saline treatments, irrespective of the application of *Bacillus subtilis* and extra Ca. As a result, the WUE as g yield of buds per l supplied water decreased to 1.20 in the salinity but developed to be 1.44

by supplementary Ca and 1.55 with *Bacillus* inoculation. The addition of *Bacillus subtilis* and supplemental Ca increased WUE under saline conditions to 20 and 29%, respectively compared to salinity treatment without further additives.

Table 4.16 Effect of nutrient and *Bacillus subtilis* additive on water measurements of salt-stressed artichoke compared to the non-saline control

Treatments	Supplied water [**l plant^{-1}**]	Drained water [**l plant^{-1}**]	Drained water [**%**]	Net consumption [**l plant^{-1}**]	Water use efficiency [**g l^{-1}**]
No salinity	752.9	434.5	57.7	318.4	2.32
Salinity only	713.1	537.0	75.3	176.1	1.20
Salinity + Ca	762.7	582.5	76.4	180.2	1.44
Salinity + Bacillus	752.6	571.8	76.0	180.8	1.55

4.3.2.4 Bud traits

The application of NaCl to the nutrient solution depressed the morphological-physical traits of the main and secondary buds. Bud weight, diameter and length (Table 4.17) and weight of the edible part (Figure 4.18) were reduced by the salinity treatment. Inoculation with *Bacillus subtilis* improved weight, length and diameter of main buds and length and diameter of secondary buds of salt-stressed plants compared to salinity only. Additional Ca into saline nutrient solution increased length and diameter of main and secondary buds compared to salinity only, however, the increases in length and diameter of main buds were not significant. While, no significant difference was detected between both *Bacillus subtilis* and additional Ca in their effects on diameter of secondary buds.

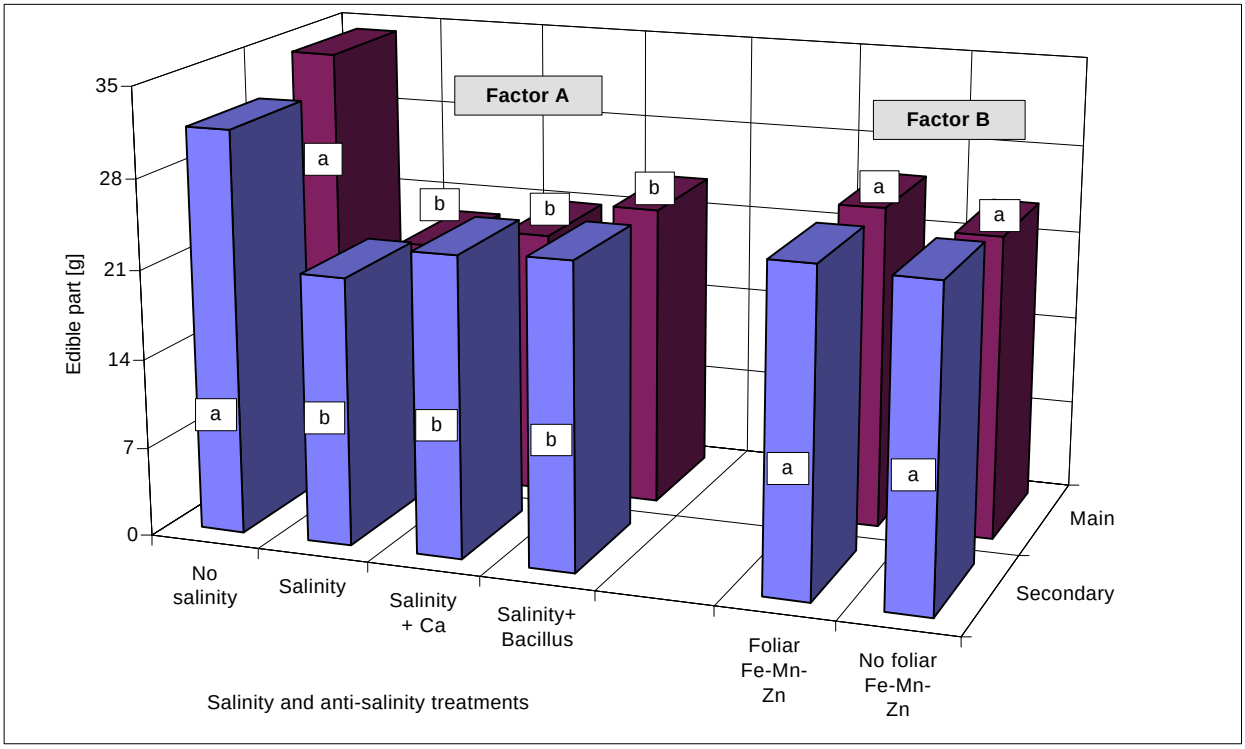
Concerning the foliar application of micronutrients (Fe-Mn-Zn), results show no statistical effect on bud characters and edible part of buds, except superiority in diameter of the main bud compared to the unsprayed treatment.

The effect of the interaction between the two factors of EC of nutrient solution and foliar application of micronutrients on bud traits was not statistically significant (Appendix 3).

Table 4.17 Effect of nutrient and *Bacillus subtilis* additive on the traits of main and secondary buds of salt-stressed artichoke compared to the non-saline control

Treatments	Main bud			Secondary bud		
	Weight [**g**]	Length [**mm**]	Diameter [**mm**]	Weight [**g**]	Length [**mm**]	Diameter [**mm**]
Factor A:						
No salinity	169.2 a	85.6 a	75.9 a	166.2 a	88.0 a	74.4 a
Salinity only	98.0 c	66.0 c	59.5 c	110.8 b	70.5 d	63.4 c
Salinity + Ca	102.7 c	69.4 bc	61.4 bc	123.8 b	74.8 c	68.5 b
Salinity + Bacillus	116.6 b	74.8 b	62.8 b	124.6 b	78.0 b	69.8 b
Factor B:						
Foliar Fe-Mn-Zn	124.1 a	75.3 a	65.8 a	131.6 a	78.1 a	69.4 a
No foliar Fe-Mn-Zn	119.1 a	72.6 a	64.0 b	131.0 a	77.5 a	68.6 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$



Means within each factor followed by the same letter are not significantly different at $P<5\%$

Figure 4.18 Effect of nutrient and *Bacillus subtilis* additive on the weight of edible part of main and secondary buds of salt-stressed artichoke compared to the non-saline control

4.3.2.5 Chemical composition

4.3.2.5.1 Soil analysis

The obtained results, which are illustrated in Table 4.18, show sharp increase in electric conductivity (EC) of soil by application of NaCl into the nutrient solution compared to the untreated control, and irrespective of the additional application of *Bacillus subtilis* or extra Ca as well as foliar spray of micronutrients. However, inoculation of stressed plants with *Bacillus subtilis* induced a decrease soil EC 4, 8 and 12 weeks.

The content of both Cl (Table 4.19) and Na (Table 4.20) in soil was much higher in the salinity treatments (6.5 dS m^{-1}) during the growing season compared to non-saline control. The treatment of salt-stressed plants with *Bacillus subtilis* decreased the content of Cl in the soil at all measurement times and Na 4, 8, 10 and 12 weeks compared to saline treatment only. The same lower trend occurred with extra Ca, except 2 weeks after treatments start when the Cl content in the soil was even higher than the saline control. However, the differences between *Bacillus subtilis* and extra Ca were not enough to be significant for Cl 10 and 12 weeks and for Na 4, 8 and 12 weeks after treatments start.

Table 4.18 Effect of nutrient and *Bacillus subtilis* additive on soil electrical conductivity (EC, dS m^{-1}) in the 1:10 soil:water extract of salt-stressed artichoke compared to the non-saline control 2 to 12 weeks after treatments start

Treatments	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A:						
No salinity	0.28 b	0.32 d	0.36 b	0.37 d	0.35 b	0.36 c
Salinity only	0.62 a	1.14 a	0.72 a	0.75 a	0.60 a	0.59 ab
Salinity + Ca	0.60 a	0.95 b	0.68 a	0.68 b	0.60 a	0.61 a
Salinity + Bacillus	0.58 a	0.83 c	0.67 a	0.60 c	0.57 a	0.53 b
Factor B:						
Foliar Fe-Mn-Zn	0.52 a	0.83 a	0.60 a	0.60 a	0.53 a	0.53 a
No foliar Fe-Mn-Zn	0.51 a	0.79 b	0.61 a	0.59 a	0.53 a	0.52 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.19 Effect of nutrient and *Bacillus subtilis* additive on Cl content in the soil (mg kg^{-1}) of salt-stressed artichoke compared to the non-saline control 2 to 12 weeks after treatments start

Treatments	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A:						
No salinity	41.5 d	35.5 d	39.0 c	36.0 d	36.0 c	33.0 c
Salinity only	945.8 b	1654.2 a	703.3 a	789.5 a	693.3 a	706.3 a
Salinity + Ca	1142.3 a	1179.5 b	657.0 a	615.8 b	554.2 b	572.7 b
Salinity + Bacillus	803.8 c	848.8 c	543.0 b	501.7 c	421.7 b	566.0 b
Factor B:						
Foliar Fe-Mn-Zn	700.9 b	877.9 a	458.4 b	474.5 a	413.8 a	464.0 a
No foliar Fe-Mn-Zn	765.8 a	981.1 a	512.8 a	497.0 a	438.8 a	475.0 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.20 Effect of nutrient and *Bacillus subtilis* additive on Na content in the soil (mg kg^{-1}) of salt-stressed artichoke compared to the non-saline control 2 to 12 weeks after treatments start

Treatments	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A:						
No salinity	211.7 b	150.8 c	172.0 b	158.3 c	167.3 d	166.7 c
Salinity only	933.8 a	1210.0 a	761.2 a	957.7 a	869.8 a	1057.7 a
Salinity + Ca	943.7 a	826.7 b	757.8 a	649.5 b	608.7 b	740.7 b
Salinity + Bacillus	857.5 a	839.8 b	754.3 a	610.8 b	479.0 c	753.3 b
Factor B:						
Foliar Fe-Mn-Zn	723.5 a	725.9 b	601.7 b	571.8 b	532.7 a	667.1 a
No foliar Fe-Mn-Zn	749.8 a	787.8 a	621.0 a	616.3 a	529.8 a	692.1 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

The foliar application of Fe-Mn-Zn did not affect the Cl content of the soil, except decreasing tendency 2 and 6 weeks after spraying compared to unsprayed treatment (Table 4.19). Also, Na content was lower when Fe-Mn-Zn was sprayed 4 to 8 weeks after treatments start (Table 4.20).

Concerning K content in the soil, results show no significant differences between the saline and non-saline control treatments, except a reduction 4 weeks after treatments start by salinity (Table 4.21). Compared to non-saline control and salinity only, *Bacillus subtilis* treatment increased K in the soil at all measurement times, except 2 weeks after treatments start. Also, extra Ca in the nutrient solution 6 and 10 weeks after treatments start enhanced the content of K in the soil compared to non-saline control and salinity only. However, the differences between *Bacillus subtilis* and extra Ca on soil content of K were not significant 6 and 10 weeks after treatments start.

Generally, soil content of K remained unchanged by foliar application (Table 4.21). With exception that little increase 6 weeks after spraying of micronutrients.

Table 4.21 Effect of nutrient and *Bacillus subtilis* additive on K content in the soil (mg kg^{-1}) of salt-stressed artichoke compared to the non-saline control 2 to 12 weeks after treatments start

Treatments	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A:						
No salinity	63.0 a	108.7 b	75.5 b	73.8 b	58.7 b	43.0 b
Salinity only	47.5 a	82.5 c	68.3 b	56.5 b	64.8 b	42.8 b
Salinity + Ca	60.0 a	111.5 b	109.5 a	56.3 b	94.7 a	54.0 b
Salinity + Bacillus	63.8 a	132.2 a	146.5 a	108.8 a	96.8 a	79.7 a
Factor B:						
Foliar Fe-Mn-Zn	55.9 a	105.4 a	106.1 a	71.7 a	78.7 a	55.2 a
No foliar Fe-Mn-Zn	61.3 a	112.0 a	93.8 b	76.1 a	78.8 a	54.6 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

The content of Ca tended to decrease in the soil in all salinity treatments (6.5 dS m^{-1}) compared to non-saline control. However, the content of Ca in the soil was not affected 2, 6 and 12 weeks after treatments start by all studied treatments (Table 4.22). Application of extra Ca via saline nutrient solution or inoculation of salt-stressed plants with *Bacillus subtilis* increased Ca content in soil 8 weeks after treatments start compared to only saline treatment without further additives.

Table 4.22 Effect of nutrient and *Bacillus subtilis* additive on Ca content in the soil (mg kg^{-1}) of salt-stressed artichoke compared to the non-saline control 2 to 12 weeks after treatments start

Treatments	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A:						
No salinity	131.5 a	116.0 a	121.3 a	127.7 a	172.8 a	117.8 a
Salinity only	124.3 a	74.0 b	106.2 a	101.7 c	136.8 b	104.2 a
Salinity + Ca	127.3 a	83.5 b	101.5 a	116.5 b	136.5 b	115.2 a
Salinity + Bacillus	128.0 a	87.7 b	97.0 a	109.7 bc	131.5 b	112.5 a
Factor B:						
Foliar Fe-Mn-Zn	129.7 a	87.3 a	107.5 a	113.5 a	144.9 a	114.6 a
No foliar Fe-Mn-Zn	125.9 a	93.3 a	105.5 a	114.3 a	143.9 a	110.3 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

No effect of foliar application of micronutrients on the content of Ca in the soil was detected during the growing season (Table 4.22).

The interaction treatments of different EC of nutrient solution and foliar application of micronutrients had no significant effect on EC of soil (Appendix 4). Irrespective of spray and unsprayed treatments, the lowest content of Cl and Na in the soil was always obtained by non-saline treatment (Appendix 4). While, Cl (4, 6 and 12 weeks) and Na (4, 6, 8 and 10 weeks) were high under salinity without further additives. Under foliar application, K was high in the soil 12 weeks after treatments start with inoculation salt-stressed plants by *Bacillus subtilis* (Appendix 5). Ca content in the soil 10 weeks after treatments start was

higher by non-saline treatment with or without foliar spraying than all saline treatments with or without further additives (Appendix 5).

4.3.2.5.2 Plant analysis

Data presented in Table 4.23 and 4.24 exhibit the effect of nutrient and *Bacillus subtilis* additives on the content of Cl and Na in the different parts of salt-stressed plants, respectively. The obtained results demonstrate sharp increases of both Cl and Na contents in all plant parts by application of NaCl to the nutrient solution compared to the non-saline control. Inoculation of stressed plants with *Bacillus subtilis* tended to reduce Cl and Na in the 4th-youngest leaf 4 and 6 weeks after treatments start and in shoots, Cl content in roots and Na content in the edible part of secondary buds. Application of extra Ca did not affect the content of Cl in any plant tissue, except increase the Cl content in the edible part of secondary buds. The additional of Ca to the nutrient solution reduced Na content in the 4th-youngest leaf 2, 4 and 6 weeks and in shoots 12 weeks after treatments start. In contrast, the content of Na in both edible part of main buds and roots was not affected by saline conditions with or without further additives of extra Ca and *Bacillus subtilis* compared to the non-saline control.

Table 4.23 Effect of nutrient and *Bacillus subtilis* additive on Cl content (% DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	1.02 b	0.86 c	0.96 c	0.47 b	0.52 c	0.98 c	0.47 b
Salinity only	3.88 a	4.21 a	3.12 a	1.33 a	1.53 b	5.39 a	0.64 a
Salinity + Ca	3.15 a	4.41 a	2.97 a	1.28 a	1.71 a	5.21 ab	0.61 a
Salinity + Bacillus	3.34 a	3.84 b	2.67 b	1.42 a	1.52 b	4.64 b	0.55 ab
Factor B:							
Foliar Fe-Mn-Zn	2.74 b	3.44 a	2.49 a	1.10 a	1.29 a	4.32 a	0.57 a
No foliar Fe-Mn-Zn	2.95 a	3.22 b	2.37 a	1.15 a	1.35 a	3.79 b	0.57 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.24 Effect of nutrient and *Bacillus subtilis* additive on Na content (% DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	4th-leaf at each 2 weeks			Edible part		Shoots	Roots
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	0.85 c	0.71 c	0.44 c	0.36 a	0.19 c	1.09 c	0.41 a
Salinity only	3.09 a	3.54 a	2.13 a	0.56 a	0.78 a	4.80 a	0.57 a
Salinity + Ca	2.59 b	3.06 b	1.70 b	0.34 a	0.76 a	3.84 b	0.48 a
Salinity + Bacillus	3.15 a	2.90 b	1.67 b	0.34 a	0.62 b	3.79 b	0.47 a
Factor B:							
Foliar Fe-Mn-Zn	2.32 a	2.65 a	1.58 a	0.41 a	0.59 a	3.68 a	0.52 a
No foliar Fe-Mn-Zn	2.51 a	2.45 a	1.39 b	0.39 a	0.58 a	3.08 b	0.44 b

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

With regard to the effect of mixture foliar application of Fe, Mn and Zn on Cl content, a decrease in the 4th-youngest leaf 2 weeks after treatments start and increases in the 4th-youngest leaf 4 weeks and in shoots 12 weeks after treatments start, respectively were observed (Table 4.23). On the other hand, Na content increased in the 4th-youngest leaf 6 weeks and in shoots and roots 12 weeks after treatments start by foliar spray treatment (Table 4.24).

The obtained results indicate that saline nutrient solution (6.5 dS m^{-1}) decreased K content in the 4th-youngest leaf 4 and 6 weeks after treatments start and in edible part of main buds (Table 4.25). *Bacillus subtilis* enhanced K content in the 4th-youngest leaf 4 and 6 weeks after treatments start and in edible part of secondary buds. The same trend was obtained with additional Ca in the 4th-youngest leaf 6 weeks after treatments start and in edible part of secondary buds.

Data presented in Table 4.26 show the effect of nutrient and *Bacillus* additive on Ca content in different parts of stressed plants. Ca content in edible part of main and secondary buds was significantly lower with the saline treatments compared to non-saline control, although Ca content in the 4th-youngest leaf was not affected by all treatments.

Also, this decrease in Ca content was found in shoots and roots at the end of season. Compared to only salinity, application of supplementary Ca into the saline nutrient solution raised the content of Ca in edible part of main buds and shoots. The same increase trend occurred in the edible part of main buds by inoculation of salt-stressed plants with *Bacillus subtilis*. But this inoculation led to a decrease of the Ca content in the roots 12 weeks after treatments start.

Only minor differences appeared among all treatments concerning the content of Mg in plant parts (Table 4.27). There was a tendency that salinity decreased the content of Mg in the 4th-youngest leaf 4 weeks after treatments start, in edible part of secondary buds and in shoots, without any positive effect to application of neither extra Ca nor *Bacillus subtilis*.

Concerning the effect of foliar application of micronutrients (Fe-Mn-Zn), K content in neither plant part was affected (Table 4.25). However, micronutrient spray raised the Ca content in the 4th-youngest leaf 4 weeks after treatments start and in edible part of main buds (Table 4.26). Also, increases in the content of Mg in the 4th-youngest leaf and shoots 6 and 12 weeks after treatments start, respectively, and in edible part of main buds were attributed to micronutrients spray (Table 4.27).

Table 4.25 Effect of nutrient and *Bacillus subtilis* additive on K content (% DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	3.16 a	3.53 a	3.42 b	4.59 a	3.40 b	3.59 a	0.80 a
Salinity only	3.47 a	2.96 b	2.87 c	3.29 b	3.25 b	3.55 a	0.82 a
Salinity + Ca	3.34 a	2.89 b	3.92 a	3.46 b	3.63 ab	4.07 a	0.89 a
Salinity + Bacillus	3.44 a	3.80 a	4.08 a	3.85 b	3.93 a	4.08 a	0.93 a
Factor B:							
Foliar Fe-Mn-Zn	3.38 a	3.35 a	3.69 a	3.83 a	3.77 a	3.91 a	0.87 a
No foliar Fe-Mn-Zn	3.32 a	3.24 a	3.46 a	3.56 a	3.54 a	3.74 a	0.85 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.26 Effect of nutrient and *Bacillus subtilis* additive on Ca content (% DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	1.34 a	1.32 a	0.86 a	0.29 a	0.20 a	1.83 a	0.39 a
Salinity only	1.00 a	1.03 a	0.67 a	0.19 b	0.16 b	1.22 b	0.26 b
Salinity + Ca	1.33 a	1.30 a	0.79 a	0.24 ab	0.17 b	1.79 a	0.29 b
Salinity + Bacillus	1.25 a	1.18 a	0.68 a	0.23 ab	0.16 b	1.45 b	0.18 c
Factor B:							
Foliar Fe-Mn-Zn	1.21 a	1.28 a	0.80 a	0.26 a	0.17 a	1.65 a	0.29 a
No foliar Fe-Mn-Zn	1.25 a	1.14 b	0.70 a	0.21 b	0.17 a	1.49 a	0.27 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.27 Effect of nutrient and *Bacillus subtilis* additive on Mg content (% DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	0.31 a	0.29 a	0.21 a	0.28 a	0.21 a	0.42 a	0.15 a
Salinity only	0.22 a	0.17 b	0.17 a	0.18 a	0.14 b	0.27 b	0.10 a
Salinity + Ca	0.23 a	0.19 b	0.17 a	0.14 a	0.17 b	0.27 b	0.10 a
Salinity + Bacillus	0.28 a	0.20 b	0.19 a	0.19 a	0.14 b	0.32 b	0.11 a
Factor B:							
Foliar Fe-Mn-Zn	0.25 a	0.22 a	0.20 a	0.22 a	0.17 a	0.35 a	0.13 a
No foliar Fe-Mn-Zn	0.26 a	0.21 a	0.18 b	0.18 b	0.16 a	0.29 b	0.10 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

The content of the micronutrients Fe, Mn and Zn in different parts of artichoke is exhibited in Table 4.28, 4.29 and 4.30, respectively. The content of those micronutrients was not influenced by EC treatments of nutrient solution. The results show no significant differences among saline nutrient solution, supplementary Ca into saline nutrient solution and inoculation of salt-stressed plants with *Bacillus subtilis* in their effects on the content of Fe, Mn and Zn in all plant parts, e.g., 4th-youngest leaf, edible part of main and secondary buds, shoots and roots compared to non-saline control. Only, salinity with or without additional application of Ca or *Bacillus subtilis* decreased the content of Fe in roots compared to the non-saline control. Also, the content of Mn in the 4th-youngest leaf decreased by supplementary Ca into saline nutrient solution 6 weeks after treatments start compared to the other treatments. In contrast, Mn content was higher in the edible part of main and secondary buds by inoculation of salt-stressed plants with *Bacillus subtilis* and application of supplementary Ca, respectively.

On the other hand, mixture foliar application of Fe, Mn and Zn increased the content of those elements in all plant parts compared to unsprayed treatment (see Table 4.28, 4.29 and 4.30). However, no statistically positive effects on Fe in the 4th-youngest leaf 4 weeks after treatments start and in edible part of main and secondary buds and Zn in edible part of secondary buds and roots were determined.

The interaction between both studied factors had little effect on nutrient content of the different plant parts (see Appendix 6, 7 and 8). However, the lower content of Cl and Na was obtained by non-saline treatment with or without foliar application of micronutrients (Fe-Mn-Zn). While saline nutrient solution without further additives, irrespective of spraying of micronutrients raised the content of Cl in shoots and roots and Na in the 4th-youngest leaf 2 weeks and shoots (Appendix 6). The content of Ca and Mg increased by treatment of non-saline nutrient solution with spraying of micronutrients in the edible part of main buds compared to other interaction treatments (Appendix 7). Also, the same trend was found concerning the content of Fe in roots (Appendix 8). While, no significant effect on the content of K, Mn and Zn was detected among the interaction treatments (Appendix 7 and 8).

Table 4.28 Effect of nutrient and *Bacillus subtilis* additives on Fe content (mg kg^{-1} DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	60.5 a	49.2 a	102.2 a	55.3 a	44.0 a	106.0 a	154.7 a
Salinity only	51.5 a	48.8 a	63.7 a	38.2 a	37.8 a	117.8 a	105.5 b
Salinity + Ca	56.3 a	43.3 a	75.3 a	33.5 a	42.3 a	136.8 a	89.7 b
Salinity + Bacillus	58.0 a	51.7 a	77.0 a	32.5 a	39.7 a	142.0 a	99.2 b
Factor B:							
Foliar Fe-Mn-Zn	69.9 a	53.2 a	99.0 a	42.1 a	41.0 a	152.3 a	126.8 a
No foliar Fe-Mn-Zn	43.3 b	43.2 a	60.1 b	37.7 a	40.9 a	99.0 b	97.7 b

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.29 Effect of nutrient and *Bacillus subtilis* additives on Mn content (mg kg^{-1} DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	154.0 a	120.0 a	238.3 a	32.7 c	17.2 b	266.3 a	41.8 a
Salinity only	177.7 a	134.2 a	194.0 a	31.2 c	21.0 ab	258.0 a	25.5 a
Salinity + Ca	144.7 a	102.7 a	145.0 b	37.3 b	24.8 a	213.8 a	25.7 a
Salinity + Bacillus	123.5 a	122.3 a	226.8 a	46.3 a	20.7 b	217.2 a	22.8 a
Factor B:							
Foliar Fe-Mn-Zn	266.1 a	204.7 a	359.9 a	44.1 a	23.9 a	387.9 a	35.5 a
No foliar Fe-Mn-Zn	33.8 b	34.9 b	42.2 b	29.7 b	17.9 b	89.7 b	22.4 b

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

Table 4.30 Effect of nutrient and *Bacillus subtilis* additives on Zn content (mg kg^{-1} DW) in different plant parts of salt-stressed artichoke compared to the non-saline control

Treatments	**4th-leaf at each 2 weeks**			**Edible part**		**Shoots**	**Roots**
	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
Factor A:							
No salinity	153.7 a	152.8 a	230.0 a	46.3 a	110.0 a	292.3 a	70.8 a
Salinity only	109.3 a	113.3 a	213.0 a	47.5 a	78.5 a	257.8 a	52.8 a
Salinity + Ca	157.5 a	135.7 a	208.5 a	57.3 a	65.5 a	221.7 a	62.7 a
Salinity + Bacillus	176.2 a	167.7 a	204.0 a	53.8 a	68.0 a	294.0 a	68.2 a
Factor B:							
Foliar Fe-Mn-Zn	237.5 a	210.3 a	320.9 a	60.0 a	87.8 a	401.3 a	73.4 a
No foliar Fe-Mn-Zn	60.8 b	74.5 b	106.8 b	42.5 b	73.2 a	131.7 b	53.8 a

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$

5. DISCUSSION

5.1 Irrigation experiment

5.1.1 Vegetative growth characters

Increasing application rates of irrigation water positively influenced vegetative growth characters of artichoke plants. The obtained results as assessed at 90, 120 and 150 days after planting exhibited that height of plant, number of leaves per plant, fresh and dry weight as well as area of the 4th-youngest leaf and leaf chlorophyll content were generally increased progressively with increasing the amount of supplied water from 50% to 100% of pan evaporation in both seasons. Application rate according to 125% of pan evaporation had no further increases, with tendency to decrease most vegetative growth characters.

The enhancing effect of increasing irrigation rates on plant growth can be explained by the fact that water is a major constituent of growing plant tissues and many biochemical processes. Water has a crucial role in the process of photosynthesis and acts as a translocating agent of organic and mineral constituents. Hence, the size and turgor of the cells increase, resulting in increases of vegetative growth.

On the other hand, the restriction of growth under water deficits was reported by Sharp (1996). Generally, growth is cell division and cell enlargement with water absorption, which is limited under the lowest irrigation rate (50% of pan evaporation). Growth reduction is the result of decrease of photosynthesis, where inhibition of net photosynthesis is closely correlated with leaf water potential and stomatal closure. Metabolic inhibition of photosynthesis under water stress may also result in part from lower diffusion of CO_2 across the leaf mesophyll (Flexas and Medrano, 2002). Slight differences were detected in physiological response to varying water application rates. By decreasing water quantities from 100 to 50% of evapotranspiration, stomatal conductance and leaf transpiration of artichoke plants decreased by 3 and 14%, respectively (Foti *et al.,* 2000). While, the obtained results by Cosentino and Mauromicale (1990) did not show any significant differences in these measurements between the same water regimes of 50 and 100% of evapotranspiration for two different genotypes of artichoke.

On the other side, the adverse effect of excessive water at 125% of pan evaporation was most likely due to the leaching of nutrients to soil layers below the rooting zone, especially because this trial was conducted in sandy soil.

5.1.2 Bud yield and bud traits

With regard to the effect of water regimes on the yield of buds and bud traits, the results showed that application of water at 100% of pan evaporation resulted in the highest total yield of buds per plant (2.82-3.16 kg) in both seasons and early yield (0.84 kg/plant) in the 1st season.

Generally, bud traits, e.g., weight, diameter and length as well as weight of edible part did not change with increasing water rates from 75 to 125% of pan evaporation. Conversely, the lowest application rate of 50% of pan evaporation was always inferior concerning the yield of buds and all bud traits.

The beneficial effect of applied water at 100% of pan evaporation on plant vegetative growth resulted in more accumulation of dry matter which is possibly the main reason for bud yield increases and improvement of bud traits.

A similar trend to increase bud yield with increasing irrigation water was reported by many authors (Pellicciari and Sismondo, 1976; Litrico *et al.*, 1998; Macua *et al.*, 2000). But Foti *et al.* (2000) found only slight reduction (6%) in bud yield by supplying water with 50% of evapotranspiration compared to 100% treatment. Conversely, 150% of evapotranspiration showed an increase in the number of buds compared to 100% (Tarantino *et al.*, 2000).

This contrasting behaviour in the response to water treatments was probably due to cultivars and its propagation method, weather conditions and the method of irrigation.

5.1.3 Water use

The drained water collected in lysimeters was progressively increased with increasing of irrigation treatments from 75 to 125% of pan evaporation. On the other side, no drained water was obtained by the lowest irrigation rate according to 50% of pan evaporation. In contrary, the electrical conductivity (EC) of drained water gradually decreased by increasing water supply from 75 to 125% of pan evaporation. The obtained results are logic based on supplied water doses, where the highest drained water was obtained with

the highest quantity of irrigation water. Also, with the same nutrition mode for varied irrigation treatments, increasing of irrigation doses should decrease EC of the drained water.

Concerning the water use efficiency (WUE), it is evident that the quantities of application water adversely affected the WUE calculated on the basis of total bud yield, where the reduction in watering rates from 125 to 50% of pan evaporation resulted in gradual increases in WUE as g yield of buds per l supplied water. By other way, it means that the increases in supplied water unit (l) were not reflected by the same levels of increases in the bud yield unit (g) according to the law of diminishing return benefit (gain) especially by irrigation rates more than 75% of pan evaporation. Gibberd *et al.* (2003) reported that a reduction of irrigation rates from 151% to 97% of pan evaporation resulted in 17% increase in WUE when calculated for root yield of carrot. There was the potential for large gains in WUE through a reduction in irrigation volume to a lower limit of 97% of pan evaporation.

With regard to the actual K_c of artichoke, an increase was detected with increasing irrigation rates indicating that transpiration was limited with irrigation according to 50 and 75% of pan evaporation. However, actual K_c for all irrigation treatments was lower compared to the calculated K_c in the early stage of artichoke growing from September until November because the offshoots still have small biomass. Actual K_c remained lower for 50% and 75%, but was corresponding for 100% of pan evaporation (as a control) until the end of growing period. On the other hand, K_c was higher for 125% of pan evaporation treatment, which resulted in the highest net water consumption of artichoke plants.

Generally, the actual K_c of artichoke plants gradually increased with increasing vegetative growth from initial period of cultivation (0.4) and reached its maximum value (1.6) when vegetation development of plants reached the maximum rate. Subsequently, there was a tendency of decreasing K_c value, and then it remained almost constant (1.1) with slight a decrease during the generative stage until the end of growing season.

The obtained results are in accordance with the sequence trend of estimated K_c for artichoke (cv. 044, seed-propagated) by Boari *et al.* (2000) using weighing lysimeters. Also, Prados (1989) measured the changes of K_c values for several fruity vegetable crops, e.g., tomatoes, peppers, cucumbers, beans, trained melons and watermelons. K_c followed the same rules

with initial values of 0.2-0.3 increasing to 1.0-1.2 and then reducing to 0.8-0.9 at the end of the growth cycle of the crop.

In conclusion, once the reference evapotranspiration (ET_o) is known by the climatological station, the obtained values of actual K_c can safely be used to predict the water requirement for artichokes cultivated in any areas to estimate the crop evapotranspiration (ET_c) under consideration of higher water consumption by annual cultivation of seed-propagated cultivars (Boari *et al.,* 2000) and lower water consumption by vegetatively propagated plants (Cosentino and Mauromicale, 1990; Boari *et al.,* 2000), especially with subsequent seasons in permanent cultivation. Boari *et al.* (2000) mentioned that water consumption of seed-propagated plants was 85% higher than vegetatively propagated plants in the same area and with similar length of cropping period. The immediate formation and rapid growth of the root and higher biomass production of the seed-propagated compared to vegetatively propagated plants could account for the different water requirements (Cosentino and Mauromicale, 1990). Furthermore, the decreases in plant water consumption from the first to the following years in permanent cultivation corresponded with vegetation vigor and yield and progressively dwindled with subsequent seasons in old permanent cultivations (Boari *et al.,* 2000).

5.1.4 Chemical composition

Regarding the effect of irrigation water regimes on chemical constituents of artichoke plants, it is evident that little responses were detected in content of total N in both 4^{th}-youngest leaf and edible part of buds with respect to irrigation treatments, where the highest N content fluctuated between treatments of 75 and 100% of pan evaporation. Conversely, the lowest content of N was obtained in the treatment of 50% of pan evaporation. This is mostly attributed to the positive effect of water on the availability of elements, subsequently their absorption and translocation. This is especially the case of nitrate, which is mainly taken up by mass flow being directly depending on soil moisture content (Marschner, 1995). On the other hand, no significant differences were shown among all four irrigation treatments concerning their effect on total P in neither 4^{th}-youngest leaf nor edible part of both main and secondary buds. This maybe is due to lower concentration of P in plant tissues and lower mobility of P compared to N (NO_3) as well as little changing in the local availability of P in the soil, because P is mainly taken up by the

diffusion (Marschner, 1995). The content of K in the 4th-youngest leaf increased with increasing the quantity of supplied water. But the irrigation treatments did not affect K content in the edible part. Except the lowest quantity of irrigation water positively influenced the content of K in edible part of main buds in the 1st season. Maybe K was effectively translocated towards the formed new buds. This assumption is emphasized by the adverse effect of the lowest quantity of irrigation water on K content in the 4th-youngest leaf at 120 days after planting, which was after the initiation of the generative stage.

Concerning the effect of irrigation treatments on the content of total fiber in the edible part, there was an obvious decrease in the total fiber content in the edible part of both main and secondary buds with increasing irrigation water regimes. The excess amount of water decreased dry mater in plant tissues, thus the percentage of total fiber decreased. These results are in agreement with those of Macua *et al.* (2000) who reported that dry matter content and total fiber percentages at three periods during the harvesting time were adversely affected by application doses of irrigation water.

5.2 Fertilization experiment

5.2.1 Timing of application

The dynamic proportions of fertigation rates (via gradually decrease and increase of supplied N and K, respectively, with age of plants) showed a certain trend to increase vegetative growth characters of artichoke plants expressed as plant height, fresh and dry weight of the 4th-youngest leaf and its area as well as chlorophyll content, where combined applications of 300 kg N and K at 400 kg K_2O ha^{-1} (dynamic rates) generally achieved superiority in all vegetative growth characters compared to the control treatment with a constant application of the same rates in both seasons. Also, the dynamic rates produced higher yields of early buds (0.56-0.61 kg/plant) and total buds (1.88-1.99 kg/plant) than constant rates, which produced lower yield of both early buds (0.45-0.54 kg/plant) and total buds (1.63-1.76 kg/plant). This is due to the fact that plants received most of the nitrogen at the early period of growth, therefore, the best indices of growth were obtained. At the same time, some K was available in the soil (190 mg kg^{-1}, exchangeable K) and therefore was not limiting the plant growth. Furthermore, increasing K applications before and while beginning of generative period was appreciated to increase the bud yield with a good quality of buds.

5.2.2 Amount of application

5.2.2.1 Vegetative growth characters

Generally, vegetative growth increased with increasing of N fertilizer rates from 200 to 300 kg N ha^{-1}. In contrast, the highest N rate (400 kg N ha^{-1}) induced an increase in plant height and fresh weight of the 4th-youngest leaf at early growth stage, however, it had no considerable effect on all other characters of vegetative growth later in the growing periods in both seasons. This discrepancy may be related to the nitrogen level in the soil (13 mg NO_3-N kg^{-1} soil representing approximately 50 kg N ha^{-1}), which was sufficient under moderate N rate (300 kg N ha^{-1}). It is known that most plants are more succulent with higher quantities of nitrogen. Moreover, it confirmed that the rate of 300 kg N ha^{-1} is quite enough to obtain the best effect of artichoke growth, which corroborates with the findings of several studies (Salamah, 1997; Foti *et al.*, 2000). No corresponding increase was obtained by increasing application rates above 300 kg N ha^{-1}.

In contrast to N, K fertilization improved plant growth up to the highest rates of 500 kg in the 1st season and 450 kg K_2O ha^{-1} in the 2nd season. The positive effect of increasing K on plant growth can be attributed to the predominant role of K for expansive growth control and osmotic drive of cell expansion (Hsiao and Läuchli, 1986).

Indeed, the growth characters reached their highest values with the combined application of 300 kg N and 400-500 kg K_2O ha^{-1}. In contrary, the lowest plant growth characters were produced by the lowest combined application of 200 kg N and 300 kg K_2O ha^{-1}.

Results of the present study agree in a certain way with those reported by Elia and Santamaria (1994) who found in a container experiment that the best vegetative growth of artichoke seedlings was obtained by a moderate rate of N (130 mg N l^{-1}) and a higher rate of K (250 mg K_2O l^{-1}) in the nutrient solution. El-Abagy (1993) reported that the medium level of both N (142 kg N ha^{-1}) and K (238 kg K_2O ha^{-1}) resulted in the best vegetative growth of artichoke growing in clay soil. On the other hand, Pedreno *et al.* (1996) reported that the reduction of nitrogen application from 500 to 300 kg N ha^{-1} resulted in a reduction of total biomass of artichoke cultivated in calcareous soil. Moreover, Gerakis and Honma (1969) did not find any positive effect for K application to an organic soil described as 'Houghton muck' on plant fresh weight compared to the untreated control.

These differences to the here presented results could be interpreted by the differences on the levels of available N and K in the soil (see Table 5.1) according to the varying yield responses to N and K fertilization.

5.2.2.2 Bud yield

The early bud yield was highest (0.59-0.62 kg/plant) with N fertigation at 300 kg ha^{-1} combined with the highest rates of K (500 kg in the 1st season and 450 kg in the 2nd season of K_2O ha^{-1}). K plays an important role to promote early maturity and to improve quality of artichoke buds (Baroccio, 1969). Concerning the total yield, the presented results showed insistently that proportions of N at 300 kg and K at 400 kg K_2O ha^{-1} achieved the highest total yield of buds (1.88-1.99 kg/plant) in both seasons. With this treatment, plants developed the best growth indices so they could produce the highest yield. A general trend occurred in the 1st season where yield components of fertigated plants were lowest with the lowest N rate at 200 kg and K rate at 300 kg K_2O ha^{-1}. Likewise, the same trend was found

by application of N at the lowest rate (250 kg) or the highest rate (400 kg) irrespective of the rates of K (350-400 kg K_2O ha^{-1}) in the 2nd season. This emphasizes the role of the moderate N rate as a vital factor for artichoke productivity, also reported by Baroccio (1969). Maybe the range between the lowest (350 kg K_2O ha^{-1}) and the moderate rate (400 kg K_2O ha^{-1}) of K was not wide enough to affect the yield components.

It will be useful to compare the optimum fertilizer rates for production of highest bud yield of ours study with results from other researchers (Table 5.1).

Table 5.1 Comparison of the optimum rates of N and K (K_2O) supply for production of highest bud yield in this presented study and previous studies

Optimum supply rate kg ha^{-1}	Soil texture and availability of N and K	Leaf N content (% DW)	Leaf K content (% DW)	Edible part N content (% DW)	Edible part K content (% DW)	Reference
300 N 400 K	Silty-loam, NO_3-N: 13 mg kg^{-1} K: 190 mg kg^{-1}	4.6-4.1	4.2-3.8	3.6-2.5	4.0-3.2	Presented study
285 N	Sandy, NO_3-N: 10 mg kg^{-1} K: 91 mg kg^{-1}	2.6	2.8	2.8-2.1	2.6-2.4	Salamah (1997)
300 N	Calcareous, NO_3-N 117 mg kg^{-1} K: nd	2.6-2.4	nd	3.0-2.0	nd	Pedreno *et al.* (1996)
142 N 238 K	Clay, Total N: 0.4% K: 56 mg kg^{-1}	5.4-4.7	5.0-4.6	nd	nd	El-Abagy (1993)
200 N 0-300 K	Sandy-loam, NO_3-N: 22 mg kg^{-1} K: 266 mg kg^{-1}	4.6-3.9	3.9-2.5	nd	nd	Pomares *et al.* (1993)
150 N	Silty-clay, (alluvial) Total N: 1.3% K: 260 mg kg^{-1}	nd	nd	nd	nd	Elia *et al.* (1991)

nd means not determined

The data of bud yield in this study is in harmony with the findings of Perdo *et al.* (1983), Pedreno *et al.* (1996) and Salamah (1997) who reported that the highest bud yields were obtained by application of 320, 300 and 285 kg N ha^{-1}, respectively. The available NO_3-N in the soil by Salamah (1997) was with 10 mg NO_3-N kg soil approximately similar to this ours present study and may be a reason for the comparable optimum N rate (Table 5.1). According to the high available N in the soil (117 mg NO_3-N kg^{-1} soil), Pedreno *et al.* (1996) recommended to reduce N application from 500 to 300 kg N ha^{-1} (Table 5.1). On the other hand, Gerakis and Honma (1969) found that N fertilizer rates up to the highest rate (200 kg N ha^{-1}) in an organic soil positively influenced earliness of bud without any effect on K application. The available K in the organic soil of Gerakis and Honma (1969) study was 165 kg ha^{-1}, while available N was not determined. Elia *et al.* (1991) reported that application of N at 150 kg ha^{-1} to an alluvial silty-clay soil rich in nitrogen (1.3% total N) was sufficient to increase number and weight of buds, without any noticeable increases with application of 300 kg N ha^{-1}. Moreover, the rates of N and K at 142 kg N and 238 kg K_2O ha^{-1} proved to be quite sufficient under clay soil condition with 0.4% total N in the soil for the optimal early and total yield of buds (El-Abagy, 1993). Since the mineralization rate is impossible to estimate from total N in the soil, the very high N contents (5.0–4.6%) in the leaves indicate that the N mineralization in the soil must have been adequate to substantial by providing the growing crop with mineral N. Foti *et al.* (2000) reported that earliness and total yield of buds were better by application of 200 kg than 400 kg of N ha^{-1}. Furthermore, Pomares *et al.* (1993) noticed no positive response on the yield with N dosage higher than 200 kg ha^{-1}, where only slight differences were obtained with 400 or 600 kg N ha^{-1}. The soil contained 22 mg NO_3-N kg^{-1} soil (approximately double of available N in our soil conditions), which can explain the lower optimum N rate compared to our study.

Moreover, Pomares *et al.* (1993) reported that K fertilizers did not increase bud yield because 266 mg available K kg^{-1} soil was adequate for the optimal growth and yield of artichoke. This is evidence for the importance of soil fertility to interpret the discrepant results.

It can be concluded that application of optimal fertilizer rates can achieve high yield and enhance earliness of buds. However, the kind of soil and nutrient availability can explain

the variations among the required fertilizer rates to achieve the optimum bud yield (Table 5.1) by the various researchers.

5.2.2.3 Bud traits

Generally, application of N at 300 kg (in both seasons) and 350 kg (in the 2nd season) combined with 400 kg K_2O ha^{-1} were the best for bud characters and weight of the edible part of main and secondary buds. Morphological characteristics of artichoke buds were little affected by different proportions of fertigation treatments, suggesting that N and K were hardly limiting for bud quality under the given range of N and K_2O and environmental conditions.

The weight of main and lateral buds was not affected by adding N and K fertilizers to an organic soil (Gerakis and Honma, 1969). But, the weight of marketable buds was highest with nitrogen application at 320 kg (Prado *et al.,* 1983) and 150 kg (Elia *et al.,* 1991) of N ha^{-1} compared to the untreated control. Also, combined application of 142 kg N and 238 kg K_2O ha^{-1} positively affected the quality of bud parameters such as the weight of bud and edible part (El-Abagy, 1993). Moreover, Salamah (1997) found an improvement of bud quality, e.g., weight and length as well as the diameter of receptacle and contributed this to N fertilization rates higher than 95 kg N ha^{-1}, while increasing application rates of N from 190 to 380 kg N ha^{-1} did not show further improvement of these characters. On the other side, no noticeable effect among all supplied N rates on bud diameter and thickness of receptacle was observed by Salamah (1997).

The variability of responses to fertilizer rates can be accepted, and may be explained by soil fertility of the experimental field and intervals between studied fertilizer rates as discussed in chapter 5.2.2.2. In addition, authors who compared many fertilizer rates to untreated control mostly found positive effect of fertilizer applications. No considerable effects for the narrow intervals among fertilizer rates were detected, which is reasonable.

5.2.2.4 Chemical composition

Only small effect to different fertigation treatments on the content of nitrogen in the 4th-youngest leaf was detected. The highest leaf content of total N (4.3% DW) was attributed to the highest application of N rate at 400 kg ha^{-1} combined with the same rate of K (400 kg K_2O ha^{-1}). While the reduced application of N to 200 kg ha^{-1}, irrespective of K rates (300-

400 kg K_2O ha^{-1}), decreased N content of the leaves (3.9% DW). Also, the content of N and crude protein in the edible part of buds increased by application of 400 kg K_2O combined with N at 300, 350 or 400 kg ha^{-1} compared to 200 or 250 kg of N ha^{-1}. Hence, there was a close relationship between N content in plant tissues and application rates of N fertilizer.

Generally, chemical analysis of the 4th-youngest leaf and edible part of buds revealed that the fertigation treatments had no effect on the content of both P and K. Only slight increase in the content of K (4.1% DW) in the edible part of secondary buds occurred with the combined application of both N and K_2O at 400 kg ha^{-1} compared to other fertigation treatments. This low variation of plant chemical composition among fertilizer rates is in agreement with El-Abagy (1993) and Pomares *et al.* (1993). On the other hand, our results did not agree with those of Salamah (1997) who found that N, P and K concentrations gradually increased in the leaves and edible part of buds with increasing N applications from 95 to 380 kg ha^{-1}. This may be because the experiment of Salamah (1997) was conducted in a sandy soil and fertilization treatments were applied as soil dressing in three equal doses at 30, 45 and 60 days after planting. Pedreno *et al.* (1996) reported that although N content decreased in artichoke aerial part (shoots) by decreasing N application, N content in the edible part was not affected.

Maybe the assessment of available N and K in the soil can be interpreted with the non-variation (scarce) of nutrient composition in plant tissues (leaves and edible part) of the presented study. However, both contents of NO_3 and available K in the soil were not changed by the different fertilization treatments, which concurs with the findings of Pedreno *et al.* (1996). It seems that the plant nutrient uptake was approximately at the same level in all fertigation treatments due to the high risk of nutrient leaching at high application treatment according to the rainy weather conditions in Freising and a slope in the experimental field. The same dose of basic fertilizers before transplanting for all treatments, the weekly intervals for fertigation and the narrow range of the studied fertilizer rates may have reinforced this interpretation. Generally, nitrate and available K in the soil of presented study gradually reduced in both layers of 0-30 cm and 30-60 cm of the soil with age of plants, which corresponded with the increase in nutrient uptake for dry mater production according to Moulinier (1980) and Pomares *et al.* (1993), where high production of dry matter of artichoke resulted in high amounts of nutrients removed per unit time (Magnifico

and Lattanzio, 1976). Moreover, Moulinier (1980) found that the uptake curves for N and K_2O behaved similarly to the plant growth curve of artichoke.

The variation in the content of N and K in plant tissues of highest yielding fertilization treatment among several studies, which are presented in Table 5.1 was due to the application rates of fertilizers according to the soil texture and its fertility. For instance, the content of N and K in both leaves and edible part of buds was lower under sandy soil conditions (Salamah, 1997) compared to silty-loam soil of our experiments. In addition to the kind of soil, the difference of sampling time among previous authors may explain the discrepancies in the content of N and K in leaves and edible part. For example, Pedreno *et al.* (1996) applied the same to our recommended rate of N (300 kg N ha^{-1}) but to calcareous soil, with lower contents of N and K in leaves and edible part compared to our findings, because their samplings were taken at the end of cropping season.

Increase of fiber content in the edible part of buds was related to increasing proportions of K to N in the fertilizer treatments. For instance, the content of total fiber increased by increasing K application from 300 kg to 400 kg K_2O ha^{-1} combined with N at 200 kg for each from 7.9 to 9.2% DW of main buds. Also, by increasing K application from 400 to 450 kg K_2O ha^{-1} and decreasing N application from 400 to 300 kg N ha^{-1} as combined proportions raised fiber content from 10.0 to 11.3% DW of main buds. The same trend of fiber increase occurred from 11.0 to 12.5% DW of secondary buds by decreasing N application from 350 kg to 250 kg ha^{-1} combined with K at 400 kg K_2O ha^{-1}. This may have occurred because high N increased the tenderness of tissue, but high K increased accumulation rate of dry matter. On the other hand, El-Abagy (1993) reported that fiber content in the edible part gradually decreased with increasing application of N and K from 71 kg N and 119 kg K_2O to the threefold rate of both N and K.

In conclusion, artichoke productivity and improvement of product quality can be sustained through the application of optimal nutrient doses in balanced proportions and suitable scheduling time depending on soil fertility and plant growth stage.

5.3 Salinity experiments

5.3.1 Effect of saline nutrient solution

The identification of physiological mechanisms limiting plant growth under salt stress is a significant step in understanding and improving the salt tolerance of cultivated plants. For a better understanding of salinity actions the following scheme (Figure 5.1) of a hypothetical model of NaCl salinity actions may help. The clarity of physiological processes, which are induced by salinity, can lead to a better management of plants even under saline conditions.

5.3.1.1 Vegetative growth characters

Application of NaCl into the nutrient solution was deleterious to seedling vegetative growth expressed as height of plant, number of leaves, total leaf area and dry weight of shoots as well as dry weight of roots per seedling. Growth reduction was sharp with increasing NaCl concentration from 0 to 150 mmol l^{-1}. For example, compared to control plants, dry weight of shoots per seedling was 82, 37 and 17% by application of 50, 100 and 150 mmol NaCl l^{-1}, respectively (Figure 5.2). The same magnitude of reaction was observed for root dry weight.

Nelson (1991) reported that seedlings are more sensitive to high salt levels than established plants. The adverse effect of increasing salinity on plant growth was mainly due to the low (more negative) osmotic potential of nutrient solution, which reduced water uptake and possibly induced water deficit in plant tissues and decreased cell turgor pressure, where salinity and water stress are connected which is also in line with findings of Thompson (1986) and Mauromicale and Licandro (2002). Cell enlargement and cell wall expansion are critical processes, therefore, growth will be limited under salinity conditions.

Likewise, vegetative growth represented by plant height, number of leaves per plant, area and dry weight of the 4^{th}-youngest leaf during the growing season were depressed when the established plants were imposed to the critical level of saline nutrient solution (50 mmol NaCl l^{-1}). Furthermore, the reduction of dry weight of the epigeal biomass (shoots) at the end of the generative period was 23% compared to the non-saline control (Figure 5.3).

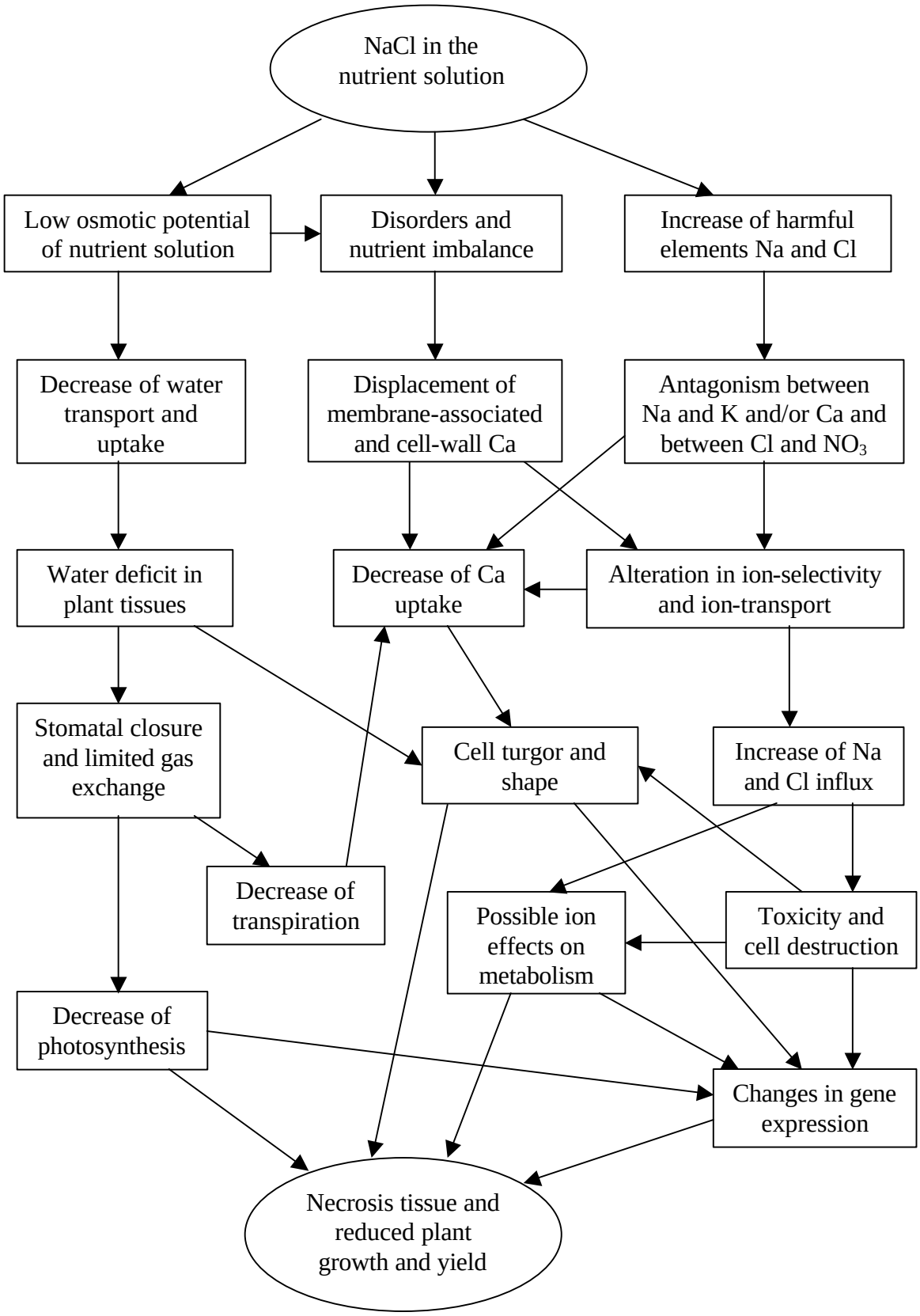


Figure 5.1 Schematic hypothetical model of the effect of NaCl salinity on the physiological processes of plants

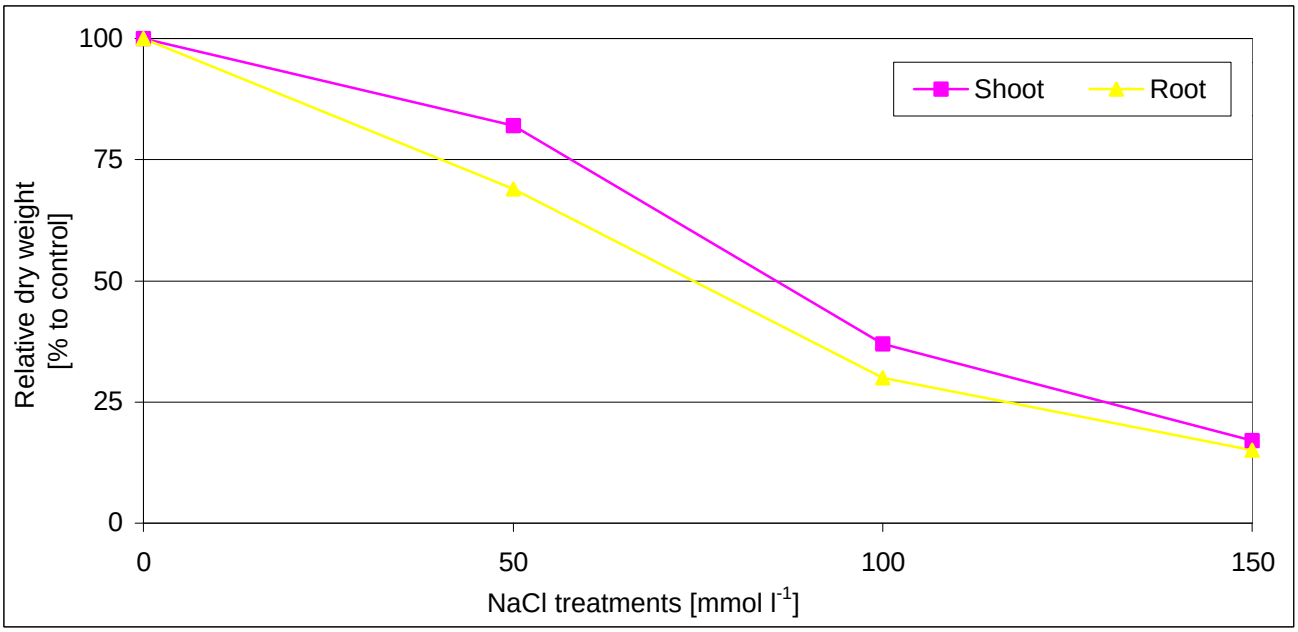


Figure 5.2 Relative biomass dry weight of salt-stressed seedlings compared to control treatment

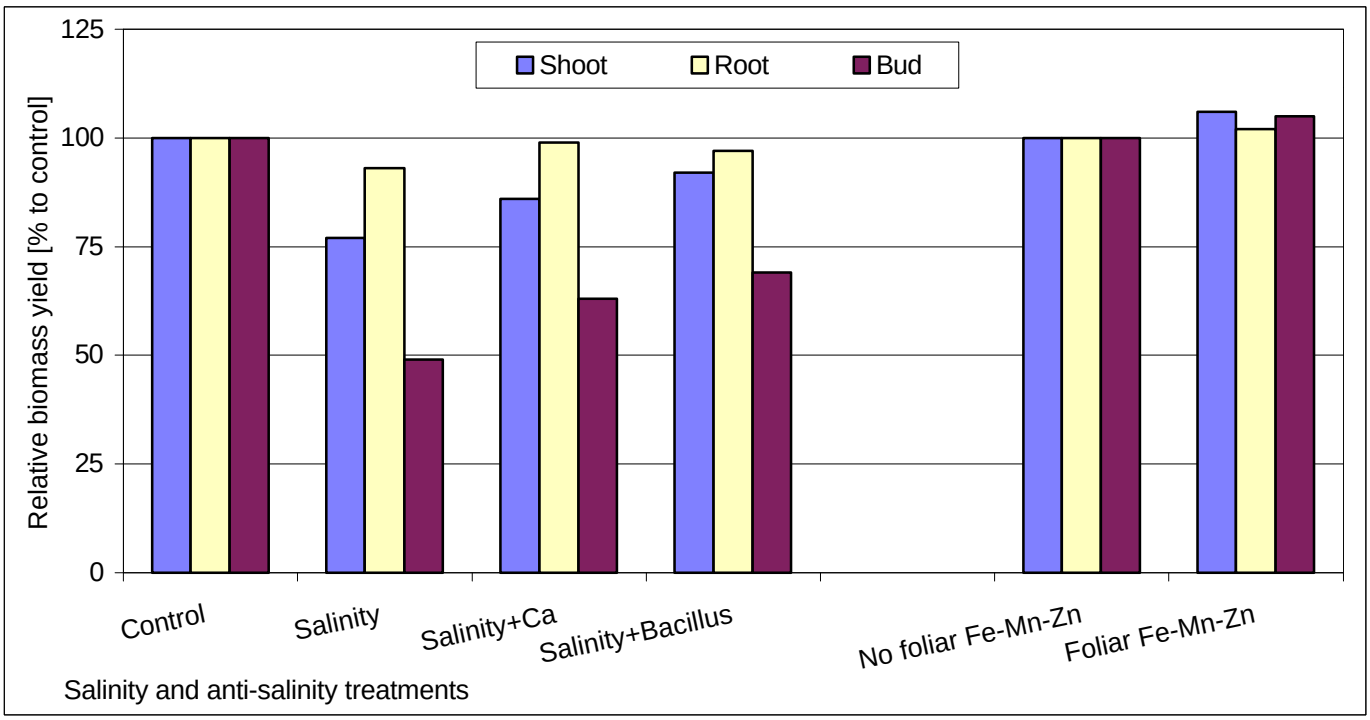


Figure 5.3 Relative biomass yield of shoots, roots and buds of salt-stressed plants compared to control treatment and additives of anti-salinity treatments

The decreased growth is primarily associated with the reduction in the net photosynthetic rate from total leaf area (Munns, 1993), which concurs with the same reduction in the net photosynthetic rate and stomatal conductance in our study. At saline conditions, the net photosynthetic rate was reduced by lowered stomatal conductance as a result of water deficit (Brugnoli and Lauteri, 1991). Thus, the amount of assimilates translocated towards the growing regions decreased. This data is in agreement with the findings of Graifenberg *et al.* (1993; 1995) who found significant reduction of total fresh and dry weight of whole plant by salinity. Also, Vincenzo *et al.* (2000) noticed that the net photosynthesis and transpiration rates were reduced progressively as EC increased. As a consequence, total biomass of leaves, offshoots and stems decreased as salinity level increased. Our results showed that the leaf photosynthesis decreased, while only little reduction in leaf transpiration was detected by salinity. This probably was due to the controlled environment (higher RH) under greenhouse conditions or because of the high amount of irrigation in the re-circulating system with high percentage of drained water that alleviated salt accumulation compared to under field conditions.

The lower transpiration rate together with the reduced leaf area and number of leaves per plant under saline nutrient solution conditions accumulated in a higher drainage rate of water. Conversely, inferiority in drained water was achieved under non-saline control compared to saline conditions, although all plants were supplied by approximately the same amount of water. This is undoubtedly the result of high water consumption according to rank growth (more vigorous) in the control treatment.

In contrast to seedling roots (see Figure 5.2), salinity did not much affect the dry weight of the underground plant-part (roots) of generative plants (see Figure 5.3), suggesting higher tolerance for this plant part to salinity compared to the other plant parts. This response is probably due to the high tolerance of external cortical root layers of established plants to presence of ion excess in re-circulating water solution in the medium (Graifenberg *et al.,* 1995), especially since salt stress started one month later after plant establishment. Also, this measurement was at the end of the generative period. It is also known that taproots and below-ground-stem become fleshy and serve as a storage organ to produce the new offshoots (Ryder *et al.,* 1983). In this concern, Graifenberg *et al.* (1993; 1995) and

Vincenzo *et al.* (2000) found that artichoke roots were less affected by salinity than other plant parts at the end of growing period.

5.3.1.2 Yield and product quality

Bud yield and number of buds per plant were more deteriorated by saline nutrient solution than vegetative growth. The weight of total bud yield per plant was 49% compared to the non-saline control (see Figure 5.3). A similar magnitude for the decrease of bud yield under saline conditions was obtained by Francois *et al.* (1991), Francois (1995), Graifenberg *et al.* (1993; 1995), De Malach *et al.* (1996) and Tarantino *et al.* (2000). Yield reduction was mainly attributed to the negative effect of salinity on the weight of buds (33-42% reduction) rather than to the number of buds per plant (17% reduction). Moreover, bud traits, e.g., weight, length and diameter as well as the weight of the edible part were highly reduced by salinity. This may be explained as a main result of adverse effects on plant growth and assimilation rate, accordingly, decreasing dry matter accumulation. Tarantino *et al.* (2000) found that the bud size was reduced, while the percentage of dry matter and fiber content increased in the buds.

5.3.1.3 Chemical composition of soil and plant tissue

Seedling-soil EC and the content of both Cl and Na in the soil gradually increased, while Ca did not vary with increasing NaCl concentration in the nutrient solution. Although, K content of seedling-soil did not show a consistent trend, the lowest content was determined with the highest salinity level (150 mmol NaCl l^{1}). The result showed gradual increase in Cl and Na in both shoots and roots of seedlings, at the same time the content of K, Ca and Mg in the shoots decreased with increasing salinity levels. These data are in harmony with the findings of Graifenberg *et al.* (1995). An increase of K was detected in the roots with increasing salinity, but tended to decrease at the highest rate of salinity (150 mmol NaCl l^{-1}). Meanwhile, the quantity for both Ca and Mg in the roots remained unchanged by salinity levels.

As mentioned above, increasing salinity level progressively increased the accumulation of Na and Cl in seedling-soil as well as root and shoot tissues of seedlings and decreased the essential nutrients. The decrease of K, Ca and Mg in the shoots was most likely due to the antagonism between Na and K or Ca at the sites of uptake in the roots and the effect of Na

on the K and Ca transport in the xylem (Cramer *et al.*, 1989; Grattan and Grieve, 1999; Cramer, 2002). As a consequence, this may have caused a disorder in nutrient distribution within plant tissues (Grattan and Grieve, 1994). Moreover, high internal concentrations of both Na and Cl in the cell can be toxic to plants (Greenway and Munns, 1980) resulting in cell destruction and growth inhibition. This assumption is emphasized by more pronounced reduction in seedling growth under the highest salinity level (150 mmol NaCl l^{-1}) and can interpret the obtained results.

The continued exposition of the established plants to the critical level of saline nutrient solution (50 mmol NaCl l^{-1}) raised soil EC and the content of both Cl and Na in the soil and gradually reduced Ca content, while K remained almost constant. A similar result was obtained by Vincenzo *et al.* (2000) who found that soil salinity increased progressively with the use of brackish water.

The content of Cl and Na in plant parts, e.g., the 4^{th}-youngest leaf, edible part of buds, roots and shoots were increased by the salinity treatment during the period of plant growth. Similar results were obtained by Francois (1995) and Graifenberg *et al.* (1995) who reported that Cl and Na were increased in artichoke organs especially in the leaves under saline conditions. The accumulation of Cl and Na in the leaves by the transpiration flow is generally a long-term process occurring in salt-stressed plants (Munns and Termaat, 1986). On the other hand, the increases in Na content in the edible part of main buds and in the roots were detected by salinity, however the differences were not significant. Sodium exclusion mechanism in the soil and high tolerance of external cortical root layers to presence of ion excess in re-circulating of nutrient solution may explain this action in the root which concurs with Graifenberg *et al.* (1995), whereas Na inclusion mechanism in the old leaves can interpret this action in the edible part of main buds. Such pattern is generally explained by the ability of older tissues to include and separate ions in the vacuoles and by the rapid rate of cell expansion in younger leaves and new buds, which results in an effective dilution of the salt in the young tissues. Salt inclusion mechanism in the old vegetative tissues seems to help the plant overcome salt stress effects, because it permits the young leaves to remain at sublethal salt concentrations and maintain their active growth and development (Yeo, 1983; Yeo and Flowers, 1982).

The content of K in the 4th-youngest leaf and in the edible part of main buds decreased by saline nutrient solution conditions, which was in agreement with data reported by Greenway and Munns (1980) and Graifenberg *et al.* (1995). Although the content of Ca in the 4th-youngest leaf was not affected, Ca content was significantly lower in the other plant parts, e.g., edible part of buds, shoots and roots under saline conditions. Maybe this occurs because the root pressure reduction caused by salinity resulted in Ca deficiencies in low transpiring tissues (Bradfield and Guttridge, 1984), which correspond to the edible part and shoots compared to the 4th-youngest leaf. On the other hand, the youngest leaves develop and expand close to the shoot apex and derive minerals mainly from the phloem, particularly as the phloem differentiates before xylem elements. The ion composition of the youngest leaves, therefore, reflects the composition of the phloem sap, which is rich in K and Ca and low in Na, even under saline condition (Delane *et al.*, 1982). The striking result from our study is that the content of micronutrients, e.g., Fe, Mn and Zn in plant tissues was not changed by salinity compared to control treatment, except that Fe decreased in the roots. Although the nutrient solution contained moderate rates of micronutrients, deficiency symptoms appeared even under non-saline control treatment. This was probably due to the high pH of the nutrient solution (>7.0), which led to decrease the availability of micronutrients. Accordingly, micronutrients uptake was limited by high pH rather than EC of the nutrient solution under the conditions of the presented study.

5.3.2 Effect of special strategies as anti-salinity measures

There are abundant evidences from numerous previous researches and the presented study that salinity alters the productivity of all higher plants. The use of tolerant cultivars and improving cropping management has the decisive role to restrict the deleterious effects of saline conditions. Salt tolerance genes function in concert with other genes that influence both quantitative traits and environmental interactions. Hence, it is not surprising that salt tolerance and yield stability are complex and quantitative genetic characters. Therefore, a good cropping system and suitable management can be effective to overcome salinity stress. To alleviate the adverse effect of salinity on artichoke production, several strategies can be followed:

5.3.2.1 Effect of the additive of *Bacillus subtilis*

Inoculation of stressed plants with *Bacillus subtilis* proved well effective to decrease the adverse effect of salinity on vegetative growth characters (Figure 5.3) and improved gas exchange leading to the increase of the net photosynthesis rate. The remarkable improvement effect of bacterization on the growth of plants under saline conditions can be attributed to the stress tolerance-inducer of *Bacillus subtilis,* which acts as plant growth and health promoter and antistressor agent (Schmiedeknecht *et al.,* 1998; Böhme, 1999; Grosch *et al.,* 1999; Bochow *et al.,* 2001). It has been hypothesized for the mode of action of *Bacillus subtilis* under salt-stress conditions that the given bacterial production of auxin and auxin precursors during root colonization induces a push in the plant auxin synthesis with changing regulation of the appropriate mechanisms (Bochow *et al.,* 2001).

Likewise, bud yield (Figure 5.3) and product quality were improved by adding *Bacillus subtilis* under saline conditions. Moreover, the water use efficiency (WUE) as g yield of buds per l supplied water increased to 129% by inoculation of stressed-plants with *Bacillus subtilis* compared to untreated saline control. This finding concurs with Bochow *et al.* (2001) who reported that *Bacillus subtilis* bacterization caused 50 and 25% reduction in salinity effect on the yield of eggplants and pepper, respectively.

Although soil EC was not affected, *Bacillus subtilis* decreased Cl and Na contents and slightly increased K and Ca in the soil, which is not logic and cannot be explained. Accordingly, inoculation of salt-stressed plants with *Bacillus subtilis* reduced Cl and Na contents in all plant parts and increased K content in the 4^{th}-youngest leaf and edible part of buds. Furthermore, an increase in Mn content in the edible part of buds was obtained by inoculation of stressed plants with *Bacillus subtilis,* while no positive effect on Mg content in all plant parts was observed. As a consequence, nutrient disorder caused by salinity was alleviated through *Bacillus subtilis* additive.

In summary, salinity affects plant growth through ionic and osmotic actions, accordingly, salinity changes the metabolism and gene expression (Cramer, 2002). The decrease of essential elements and water uptake and increase of harmful elements by salinity explain the reduction of plant productivity (Grattan and Grieve, 1994; 1999). In contrast to the essential elements, Na is not important for plant growth (Marschner, 1995). The inoculation of salt-stressed plants with *Bacillus subtilis* increased the exclusion mechanism

of harmful elements (Na and Cl) and improved the uptake of essential elements (K, Ca and Mn) for plant growth. It also stimulated the vegetative growth and accumulation of assimilation rate through improving gas exchange even under salinity conditions. The complex interactions between bacteria and plant probably improved root/nutrient conductance and may have increased ion-selectivity by special phytohormone signals, which are important for rapid osmotic adjustment to salinity. The restoring of hydraulic conductance and regulating nutrient influx through the nutrient uptake sites may also have alleviated the nutrient imbalance. Accordingly, the genetic potential can be more expressed by the presence of *Bacillus subtilis* without more adversely alteration under saline nutrient solution. Our finding can support the hypothesis of Bochow *et al.* (2001) that *Bacillus subtilis* increases plant growth and its yield even under saline conditions. However, further research should be undertaken in order to attain more understanding for other induction mechanisms of salt-stress tolerance by *Bacillus subtilis*.

5.3.2.2 Effect of additional Ca

The common treatment with the addition of Ca under saline conditions is via the roots to decrease Na/Ca ratio in the roots. In our experiment, application of supplemental Ca into saline nutrient solution enhanced plant growth (Figure 5.2). Similar improvements were obtained by supplemental Ca under saline conditions in vegetative growth of tomato (Lopez and Satti, 1996; Caines and Shennan, 1999; Navarro *et al.*, 2000) and lettuce (Bia *et al.*, 2001). This may have been due to the decrease of Na/Ca ratio in the root rhizosphere. Extra Ca can protect the cell membrane from the adverse effect of salinity (Cramer *et al.*, 1985; Cramer, 2002). Moreover, membrane permeability is improved (reduced) by supplementary Ca (Kaya *et al.*, 2002), thus the ion-selectivity is increased. As a consequence, the plant can better absorb the essential nutrients for plant growth by excluding the harmful elements, accordingly, the nutrient imbalance decreases.

An enhancement in bud yield (Figure 5.2) and product quality was obtained by adding supplemental Ca into saline nutrient solution. The water use efficiency (WUE) in g yield of buds per l supplied water was 120% by additional Ca via saline nutrient solution compared to untreated saline control. This finding concurs with Kaya *et al.* (2002) who reported that additional Ca improved strawberry productivity and WUE under saline conditions. The same trend was reported by Lopez and Satti (1996) for tomato productivity.

While, soil EC was not affected, additional Ca into saline nutrient solution decreased Cl and Na contents and slightly increased K and Ca in the soil, with little tendency to increase Cl content at the beginning of treatment period. This is probably due to the use of $CaCl_2$ as a source for the additional Ca. In this concern, Caines and Shennan (1999) reported that the additional Ca in the form of $CaSO_4$ was more preferred than $CaCl_2$ for saline-stressed tomato. Supplemental Ca in the saline nutrient solution reduced Na content in the 4th-youngest leaf and shoots, while enhanced the content of Ca in the edible part of buds and shoots, probably due to the interaction of Ca with Na transport (Cramer *et al.*, 1989; Grattan and Grieve, 1999) towards the shoots and buds by reducing Na/Ca ratio. Furthermore, extra Ca can protect cell membranes and increases the ion-selectivity (Cramer *et al.*, 1985; Cramer, 2002). Because Ca is essential for maintaining selectivity and integrity of cell membranes (Epstein, 1972), any deficiency of Ca will impair both, the ion-selectivity and the integrity of the membrane and then accelerates the passive accumulation of Na in plant tissues. Therefore, this explanation is corroborating the vital role for extra Ca to alleviate the adverse effect of salinity. A similar result was found by Kaya *et al.* (2002) who reported that Ca supplemented into saline nutrient solution raised the content of Ca in strawberry leaves.

5.3.2.3 Effect of micronutrients by foliar applications

Foliar application is increasingly used to alleviate micronutrient deficiencies at the time of translocation and uptake. The foliar application of micronutrients by means of foliar sprays offers a method of supplying nutrients to plants more rapidly than methods involving root application especially under stress conditions (Marschner, 1995). Our results showed that foliar application of a mixture of the micronutrients (Fe-Mn-Zn) resulted in a superiority of vegetative growth characters compared to the untreated control. This may be explained by the important role for those essential nutrients for plant growth and metabolism activity. Also, foliar application of micronutrients improved the early and total yield of buds. The positive effect was obvious with the weight of buds compared to unsprayed treatment (Figure 5.2), while the number of buds per plant did not change.

On the other hand, the foliar application of micronutrients (Fe-Mn-Zn) resulted in no significant differences in soil EC, with little inducement to decrease Cl and Na in the soil, which was not expected by foliar treatments. Generally, the content of K and Ca in the soil

was not affected by foliar application. This is logic because the additive of micronutrients was via foliage spray not by root system. Foliar application of micronutrients (Fe-Mn-Zn) corrected the deficiency of those nutrients in plant parts and this was expected. Slight increases in the content of Na, Ca and Mg were detected in plant tissues with spraying treatment, while the content of Cl and K remained unchanged.

In the light of these results, it can be concluded that the enhancement of artichoke productivity was attributed to the positive effect of micronutrients as essential nutrients on vegetative growth especially plant height, leaf number and its area. Thus, the assimilative leaf area increased the accumulation rate of dry matter, accordingly, the favourable effect of spraying treatment on the yield is quite expected. Our findings reinforce the recommendation that using foliar application of micronutrients under stress conditions like increased EC levels and pH of soil nutrient solution.

6. SUMMARY

The work was carried out in 1998-2002 at El-Bossily Site of Protected Cultivation, El-Behira Governorate, northern Egypt and at TU München Research Station in Dürnast, Freising, southern Germany.

The objectives of this study were:

1. Evaluation of artichoke growth, yield and product quality under different levels of water supply to set an adequate amount and to determine the actual crop coefficient (K_c) for different growth stages in Egypt.
2. Determination of the optimal proportion of N and K fertilization for cultivation of seed-propagated artichokes using drip irrigation and fertigation during summer period in Germany.
3. Evaluation of artichokes under saline conditions and to ameliorate the adverse effects of salinity by inoculation with *Bacillus subtilis*, additional Ca and/or Fe-Mn-Zn spray.

The important obtained results can be summarized as follows:

1. Irrigation experiment in Egypt, 1998/1999-1999/2000

- Amount of irrigation water affected artichoke growth during vegetative and generative phase.
- The optimum water regime was 75-100% of pan evaporation for most artichoke plant traits such as height of plant, number of leaves, fresh and dry weight of the 4th-youngest leaf and its area, chlorophyll content, bud yield ad bud quality.
- Total fiber content in the edible part of main and secondary buds decreased gradually with increasing water application rates.
- The quantity of drained water increased with increasing the amount of supplied irrigation water. The lowest irrigation rate of 50% of pan evaporation did not produce any drained water.
- Irrespective of the different water regimes, actual K_c of artichoke plants gradually increased during the growth and reached its maximum when the highest vegetation development of the crop took place, then K_c tended to decrease and remained almost constant during the generative period. Actual K_c of artichoke increased with increasing

amounts of supplied water from 50 to 125% of pan evaporation, however actual K_c was lower than calculated K_c in the first part of the growing period for all irrigation treatments. It remained lower for 50 and 75% but was corresponding for 100% of pan evaporation until the end of growing period. K_c was higher for 125% of pan evaporation treatment.

- For good water and crop management, it is recommended to irrigate artichoke plants according to 75-100% of pan evaporation in Egypt. For cultivars, which differ in propagation method, replicated studies will be useful under several weather conditions, irrigation system and soil properties.

2. Fertilization experiment in Germany, 2000-2001

- Timing and amount of N and K application played an important role in the improvement of artichoke productivity.
- The best vegetative growth and bud yield of artichoke were obtained by dynamic application of N and K which is starting with higher and subsequently decreasing rates of N and starting with lower and subsequently increasing rates of K during the fertigation period.
- The combined application of N at 300-400 kg N ha^{-1} and K at 400-500 kg K_2O ha^{-1} produced the highest plant height, number of leaves, fresh and dry weight of the 4^{th}-youngest leaf and its area as well as chlorophyll content. The poorest vegetative plant growth was obtained by either constant rates of fertigation or dynamic application of the lowest rates of both N (200 kg N ha^{-1}) and K (300 kg K_2O ha^{-1}).
- Dynamic application rates of N at 300-350 kg with K at 400-450 kg K_2O ha^{-1} insistently resulted in the highest bud yield and earliness as well as best product quality. The lowest values were produced by either application of the lowest rates of N (200 kg N ha^{-1}) and K (300 Kg K_2O ha^{-1}) or with the constant treatment of control.
- Fiber content in the edible part of buds was related to K/N ratio fertilization. Increasing proportions of K to N in the fertigation treatment resulted in superiority in fiber content in the edible part of both main and secondary buds.
- The N_{min} target value for artichoke was estimated to 400 kg N ha^{-1} based on optimum bud yield, N content in leaves and N mineralization potential of the soil. It can be recommended for the best productivity of artichoke with efficient use of fertilizers.

3. Salinity experiments in sand culture in the greenhouse, Germany, 2002

- Seedling quality, e.g., seedling height, number of leaves, total leaf area and dry weight of shoots as well as dry weight of roots sharply decreased by increasing NaCl concentration in the nutrient solution from 0 to 150 mmol l^{-1}. At the same time, EC in the soil, Cl and Na content of the soil and plant tissue increased.
- Increasing NaCl concentration in the nutrient solution increased K content in the roots, whereas Ca and Mg were not affected. Seedlings reacted to salinity by decreasing K, Ca and Mg contents in the shoots.
- Vegetative growth of established plants represented by plant height, number of leaves and area of the 4th-youngest leaf and its dry weight as well as shoots dry weight was depressed by the salinity treatment (6.5 dS m^{-1}) compared to the non-saline control. In the same way, the salinity treatment negatively affected the physiological parameters, e.g., net photosynthesis rate, stomatal conductance and transpiration. Inoculation of salt-stressed plants with *Bacillus subtilis* or addition of supplemental Ca to the saline nutrient solution alleviated the adverse effect of salinity on vegetative growth characters and improved net photosynthesis rate. *Bacillus subtilis* ranked the first, followed by supplemental Ca for improving plant height, number of leaves per plant, leaf area, dry weight, net photosynthesis rate as well as stomatal conductance. Foliar application of mixture of micronutrients (Fe-Mn-Zn) showed superiority in vegetative growth characters and net photosynthesis rate compared to the untreated control.
- Salinity treatment reduced early, marketable and total yield of buds as well as bud quality compared to the non-saline control treatment. The additives of *Bacillus subtilis* or extra Ca improved bud yield and its components under salinity conditions and alleviated the negative salinity effects on product quality. Foliar application of micronutrients (Fe-Mn-Zn) enhanced bud yield and its components compared to unsprayed treatment, but the number of buds per plant was not affected.
- Results demonstrated sharp increases of both Cl and Na contents in all plant parts by application of NaCl to the nutrient solution compared to the non-saline control. Inoculation of stressed plants with *Bacillus subtilis* tended to reduce Cl and Na content in most plant tissues. Application of extra Ca reduced Na content in the 4th-youngest leaf and in shoots, while it did not affect the content of Cl in most plant tissues.

- The content of Ca and K was lower in plant tissues under saline conditions. *Bacillus subtilis* and additional Ca enhanced K content in the 4th-youngest leaf and in the edible part of buds. Additional Ca also raised Ca content in the edible part of main buds and shoots. Foliar application of micronutrients (Fe-Mn-Zn) did not affect K content in neither plant part, while it raised the Ca content in the 4th-youngest leaf 4 weeks after treatment start and in the edible part of main buds and Mg content in the 4th-youngest leaf 6 weeks after treatments start and shoots and in the edible part of main buds.
- The content of Fe, Mn and Zn in various plant parts was almost not affected by salinity and further additives to the nutrient solution compared to non-saline control. Repeated foliar application of Fe-Mn-Zn increased the content of those elements in most plant parts compared to the unsprayed treatment.
- The interaction effects between EC of nutrient solution and additive of extra Ca or *Bacillus subtilis* (Factor A) and foliar application of micronutrients (Fe-Mn-Zn) compared to no spray (Factor B) were mostly not significant. In the cases where interaction between both factors occurred, the interaction did not follow a general pattern. However, The best productivity was obtained by repeated spraying of micronutrients under non-saline treatment.

7. ZUSAMMENFASSUNG

Die Forschungsarbeiten an Artischocken wurden 1998 bis 2002 durchgeführt am El-Bossily Site of Protected Cultivation, Nordägypten und in der Versuchsanlage Dürnast des Lehrstuhls für Gemüsebau, TU München, Süddeutschland.

Die Ziele der Studien waren:

1. Die Untersuchung der Wirkung verschiedener Bewässerungsmengen auf das Wachstum, den Ertrag und die Knospenqualität von Artischocken, um den Verlauf des aktuellen Crop Koeffizienten (K_c-Wert) während der Kultur und daraus die optimale Bewässerungsmenge unter Nordägyptischen Verhältnissen zu bestimmen.
2. Die Bestimmung der optimalen Mengen und Verhältnisse der N- und K- Düngung bei samenvermehrten Artischocken unter Anwendung von Tropfbewässerung und Fertigation in Deutschland.
3. Die Untersuchung in welchem Maße die Inokulation mit *Bacillus subtilis*, zusätzliches Ca in der Nährlösung und/oder Blattdüngung mit Fe, Mn und Zn die negativen Effekte einer Versalzung mit NaCl verringert.

Die wichtigen Ergebnisse können wie folgt zusammengefasst werden.

1. Bewässerungsversuche in Ägypten, 1998/1999 und 1999/2000

- Die Bewässerungsmenge beeinflusste das Artischockenwachstum während der vegetativen und generativen Phase.
- Die optimale Bewässerungsmenge betrug 75-100% der Pan-A Verdunstung im Hinblick auf die meisten Pflanzenmerkmale wie Pflanzenhöhe, Blattzahl, Frisch- und Trockenmasse und Fläche des viertjüngsten Blattes, Chlorophyllgehalt, Knospenertrag und Knospenqualität.
- Der Gesamt-Fasergehalt im essbaren Teil der Primär- und Sekundärknospen nahm mit steigender Bewässerungsmenge ab.
- Die Drainwassermenge nahm mit steigender Bewässerungsmenge zu, wobei die niedrigste geprüfte Bewässerungsmenge von 50% der Pan-A Verdunstung kein Drainwasser hervorbrachte.
- Ungeachtet der Bewässerungsmenge stieg der K_c-Wert während der vegetativen Wachstumsphase an, erreichte sein Maximum zu Beginn der Ernte, danach nahm er

leicht ab und blieb bis zum Ende des Erntezeitraums konstant. Der aktuelle K_c-Wert der Artischocken an einem bestimmten Zeitpunkt war umso größer je höher die Bewässerungsgabe war. Dennoch lagen in der vegetativen Phase die aktuellen K_c-Werte immer unter dem berechneten K_c-Wert. In der generativen Phase lag der K_c-Wert bei Bewässerung nach 50 und 75% der Pan-A Verdunstung unter dem berechneten, entsprach ihm bei 100% und war bei 125% höher als der berechnete K_c-Wert.

- Für ein gutes Wasser- und Kulturmanagement in Ägypten wird empfohlen, Artischocken entsprechend 75-100% der Pan-A Verdunstung zu bewässern. Weitere Versuche sind sinnvoll zur Bewertung dieser Ergebnisse, insbesondere der Vergleich von vegetativ und Samen vermehrten Artischockensorten sowie von unterschiedlichen Klimabedingungen, Bewässerungmethoden und Bodeneigenschaften.

2. Düngeversuch in Deutschland, 2000-2001

- Das Timing und die Menge an gedüngtem N und K spielten eine wichtige Rolle in der Entwicklung und Ertragsbildung bei Artischocken.
- Das beste vegetative Wachstum und der höchste Knospenertrag wurde mit dynamischen Fertigationsgaben von N und K erzielt, d.h. mit am Anfang hohen N-Gaben, die im Laufe des Fertigationszeitraums abnahmen und den zunächst niedrigen und allmählich ansteigenden K-Mengen je Fertigationsgabe.
- Die Kombinationen aus 300-400 kg N ha^{-1} und 400-500 kg K_2O ha^{-1} ergaben das beste Pflanzenwachstum erfasst als Pflanzenhöhe, Blattzahl, Frisch- und Trockenmasse des viertjüngsten Blatts zu verschiedenen Zeitpunkten sowie dessen Fläche und Chlorophyllgehalt. Das schwächste Wachstum war bei Fertigation mit konstanten N- und K-Gaben sowie mit dynamischen Gaben auf der niedrigsten geprüften Düngestufe von 200 kg N ha^{-1} und 300 kg K_2O ha^{-1}.
- Dynamische Gaben von 300-350 kg N und 400-450 kg K_2O ha^{-1} erzielten durchgehend den höchsten Gesamt-Knospenertrag, Frühertrag und die beste Knospenqualität. Die geringste Leistung in dieser Hinsicht erbrachten wiederum die konstanten N- und K-Gaben sowie die dynamischen Gaben von 200 kg N und 300 kg K_2O ha^{-1}.
- Der Gesamt-Fasergehalt im essbaren Anteil der Knospen zeigte einen Zusammenhang mit dem K/N-Verhältnis der Düngung. Ein höheres K/N-Verhältnis ergab einen höheren Fasergehalt sowohl in den Primär- als auch in den Sekundärknospen.

- Für Artischocken wurde ein Nmin-Sollwert von 400 kg N ha^{-1} abgeschätzt, abgeleitet aus dem optimalen Ertrag, dem N-Gehalt der Blätter und dem N-Mineralisierungspotenzial des Bodens.

3. Salinitätsversuche in Sandkultur im Gewächshaus, Deutschland, 2002

- Die Jungpflanzenqualität von Artischocken, d.h. Sprosshöhe, Blattzahl, Gesamtblattfläche, Spross- und Wurzeltrockenmasse nahm mit steigendem NaCl-Gehalt (0 bis 150 mmol l^{-1}) in der Nährlösung stark ab. Gleichzeitig nahm die EC im Sand und der Cl- und Na-Gehalt im Boden und in der Pflanze zu.
- Steigender NaCl-Gehalt in der Nährlösung erhöhte den K-Gehalt in den Wurzeln, der Ca- und Mg-Gehalt hingegen waren nicht beeinflusst. Im Gegensatz dazu sank der K-, Ca- und Mg-Gehalt im Spross mit steigender Salinität.
- Das vegetative Wachstum von etablierten Pflanzen, charakterisiert durch die Pflanzenhöhe, Blattzahl, Trockenmasse und Fläche des viertjüngsten Blattes (zu verschiedenen Zeitpunkten) und die Sprosstrockenmasse, wurde durch die Salzbehandlung (6,5 dS m^{-1}) vermindert im Vergleich zur unversalzten Kontrolle. Genauso beeinträchtigte die Salzbehandlung die physiologischen Funktionen wie Nettophotosynthese, stomatäre Leitfähigkeit und Transpiration. Die Inokulation der Pflanzen mit *Bacillus subtilis*, bevor sie dem Salzstress ausgesetzt wurden, oder die Zugabe von 5 mmol l^{-1} Ca in die saline Nährlösung milderten den Salzeffekt auf das vegetative Wachstum ab und verbesserten die Nettophotosyntheserate. *Bacillus subtilis* war in seiner Wirkung auf Pflanzenhöhe, Blattzahl, Blattfläche, Trockenmasse, Nettophotosyntheserate und stomatäre Leitfähigkeit dem zusätzlichen Ca in der Nährlösung überlegen. Die Blattdüngung mit Mikronährstoffen verbesserte das vegetative Wachstum und die Nettophotosynthese im Vergleich zur unbesprühten Kontrolle.
- Die Salzbehandlung verringerte den Frühertrag, marktfähigen und Gesamtertrag an Knospen sowie deren Qualität im Vergleich zur NaCl-freien Kontrolle. Die Zugabe von *Bacillus subtilis* oder Ca verbesserte den Ertrag, die Ertragskomponenten und die Knospenqualität der salzgestressten Artischocken. Die Blattdüngung mit Mikronährstoffen verbesserte ebenfalls den Ertrag und die Knospengröße, jedoch nicht die Knospenzahl im Vergleich zur unbesprühten Kontrolle.

- Im Vergleich zur NaCl-freien Kontrolle war in den salzgestressten Artischocken der Gehalt an Na und Cl in allen Pflanzenteilen drastisch erhöht. Inokulation mit Bacillus subtilis ergab tendenziell niedrigere Na- und Cl-Gehalte in den meisten Pflanzenteilen. Zusätzliches Ca in der salinen Nährlösung verringerte den Na-Gehalt im viertjüngsten Blatt zu verschiedenen Zeitpunkten und im Gesamtspross zu Kulturende. Dagegen blieben die Cl-Gehalte in den meisten Pflanzenteilen durch die Zugabe von Ca unbeeinflusst.
- Der Ca- und K-Gehalt aller Pflanzenteile war unter den salinen Bedingungen geringer. Bacillus subtilis und zusätzliches Ca erhöhten den K-Gehalt im viertjüngsten Blatt und im essbaren Teil der Knospen. Zusätzliches Ca erhöhte außerdem den Ca-Gehalt im essbaren Teil der Primärknospen und im Gesamtspross. Die wiederholte Blattdüngung mit Mikronährstoffen zeigte keine Wirkung auf den K-Gehalt verschiedener Pflanzenteile und erhöhte den Ca-Gehalt im viertjüngsten Blatt vier Wochen nach Behandlungsbeginn und im essbaren Teil der Primärknospen. Außerdem stieg durch die Blattdüngung der Mg-Gehalt im viertjüngsten Blatt sechs Wochen nach Behandlungsbeginn, im Gesamtspross und im essbaren Teil der Knospen an im Vergleich zur unbesprühten Kontrolle.
- Der Gehalt von Fe, Mn und Zn in verschiedenen Teilen der Artischocken wurde kaum durch die Salzbehandlung mit und ohne die Zugabe von *Bacillus subtilis* oder Ca beeinflusst. Die Blattdüngung mit diesen Nährstoffen erhöhte deren Gehalt in fast allen untersuchten oberirdischen Pflanzenteilen.
- Wechselwirkungen zwischen dem Salzgehalt der Nährlösung, der Zugabe von *Bacillus subtilis* oder Ca (Faktor A) und der Blattdüngung mit Mikronährstoffen im Vergleich mit fehlender Blattdüngung (Faktor B) waren nur selten signifikant. Der Vergleich der aufgetretenen Wechselwirkungen ließ kein durchgehendes Muster erkennen. Die NaCl-freie Kontrolle mit Mikronährstoff-Blattdüngung zeigte dennoch durchgehend die beste Leistung im Hinblick auf Wachstum, Ertrag und Qualität.

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9. APPENDIXES

Appendix 1: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on vegetative growth and physiological characters of artichoke plants

Interaction treatments		Plant height [**cm**]	No. of leaves/ plant	4th leaf area [**cm²**]	4th leaf dry weight [**g**]	Photosynthesis [**µmol m⁻² s⁻¹**]	Transpiration [**mol m⁻² s⁻¹**]	Stomatal conductance **[mol m⁻² s⁻¹]**
Factor A	Factor B							
		15 days after treatments start						
No Salinity	+ Spray	82.7 a	11.6 a	582.0 a	9.2 a	13.2 a	6.2 a	0.70 a
	- Spray	79.9 a	11.0 a	557.3 a	8.7 a	12.8 a	6.3 a	0.77 a
Salinity only	+ Spray	70.7 a	9.9 a	402.7 d	6.7 a	6.3 a	5.8 a	0.43 a
	- Spray	67.3 a	9.7 a	351.3 e	6.1 a	5.8 a	5.8 a	0.40 a
Salinity + Ca	+ Spray	72.7 a	10.6 a	410.3 d	7.4 a	8.8 a	6.1 a	0.49 a
	- Spray	70.1 a	9.8 a	396.8 d	7.1 a	9.2 a	6.2 a	0.46 a
Salinity + Bacillus	+ Spray	76.8 a	11.3 a	508.7 b	8.2 a	9.9 a	5.9 a	0.66 a
	- Spray	72.8 a	10.3 a	445.3 c	7.5 a	12.6 a	5.9 a	0.52 a
		30 days after treatments start						
No Salinity	+ Spray	90.3 a	15.3 a	659.0 a	11.3 a	9.8 a	6.4 a	0.40 a
	- Spray	89.1 a	14.1 a	628.9 a	10.3 a	7.9 a	6.6 a	0.39 a
Salinity only	+ Spray	76.4 a	12.5 a	481.4 a	8.6 a	3.5 a	5.7 a	0.26 a
	- Spray	72.3 a	11.5 a	463.6 a	8.0 a	3.3 a	5.6 a	0.25 a
Salinity + Ca	+ Spray	80.3 a	13.5 a	522.3 a	9.8 a	4.7 a	5.5 a	0.31 a
	- Spray	76.9 a	12.8 a	500.3 a	9.3 a	3.9 a	5.9 a	0.29 a
Salinity + Bacillus	+ Spray	84.3 a	14.1 a	573.9 a	10.6 a	6.4 a	5.8 a	0.32 a
	- Spray	81.0 a	12.7 a	545.1 a	10.0 a	4.8 a	5.8 a	0.28 a
		45 days after treatments start						
No Salinity	+ Spray	101.9 a	16.1 a	565.7 a	9.5 a	9.1 a	6.5 a	0.58 a
	- Spray	100.2 a	15.6 a	573.1 a	9.7 a	8.6 a	6.3 a	0.51 a
Salinity only	+ Spray	81.5 a	14.1 a	456.1 a	8.2 a	4.3 a	5.7 a	0.32 a
	- Spray	79.0 a	13.7 a	449.4 a	8.2 a	4.1 a	5.3 a	0.25 a
Salinity + Ca	+ Spray	87.9 a	14.9 a	480.6 a	8.9 a	5.8 a	5.8 a	0.37 a
	- Spray	82.5 a	14.4 a	440.8 a	8.6 a	5.8 a	5.8 a	0.34 a
Salinity + Bacillus	+ Spray	94.0 a	15.3 a	539.6 a	9.8 a	6.9 a	5.8 a	0.39 a
	- Spray	90.4 a	14.5 a	529.7 a	9.3 a	6.3 a	5.9 a	0.41 a

Means within each column and sampling date followed by the same letter are not significantly different at $P<5\%$

Appendix 2: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on bud yield and total dry weight of shoots and roots of artichoke plants

Interaction treatments		Early yield of buds		Total yield of buds		Marketable	Total dry weight	
Factor A	Factor B	No./plant	kg/plant	No./plant	kg/plant	yield of buds [**kg/plant**]	Shoots [**g/plant**]	Roots [**g/plant**]
No Salinity	+ Spray	2.13 a	0.43 a	10.74 a	1.79 a	1.53 a	519.2 a	119.5 a
	- Spray	1.88 a	0.27 a	10.67 a	1.71 a	1.41 a	485.5 a	117.0 a
Salinity only	+ Spray	1.04 a	0.10 a	8.93 a	0.87 a	0.58 a	399.8 a	111.0 a
	- Spray	0.87 a	0.08 a	8.75 a	0.85 a	0.57 a	377.8 a	108.6 a
Salinity + Ca	+ Spray	1.46 a	0.19 a	9.92 a	1.14 a	0.83 a	443.2 a	116.4 a
	- Spray	1.48 a	0.16 a	9.71 a	1.06 a	0.77 a	425.1 a	118.3 a
Salinity + Bacillus	+ Spray	1.25 a	0.16 a	10.13 a	1.20 a	0.92 a	470.0 a	118.2 a
	- Spray	1.23 a	0.14 a	10.09 a	1.13 a	0.83 a	449.2 a	112.1 a

Means within each column followed by the same letter are not significantly different at $P<5\%$

Appendix 3: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on the traits of main and secondary buds of artichoke plants

Interaction treatments		Weight of bud [**g**]	Length of bud [**mm**]	Diameter of bud [**mm**]	Weight of edible part [**g**]
Factor A	Factor B				
		Main bud			
No Salinity	+ Spray	171.1 a	86.9 a	77.8 a	35.4 a
	- Spray	167.2 a	84.2 a	73.9 a	33.2 a
Salinity only	+ Spray	101.2 a	67.1 a	60.1 a	19.7 a
	- Spray	94.8 a	64.9 a	58.9 a	19.0 a
Salinity + Ca	+ Spray	105.4 a	70.8 a	62.1 a	21.8 a
	- Spray	99.9 a	68.1 a	60.7 a	20.0 a
Salinity + Bacillus	+ Spray	118.9 a	76.4 a	63.1 a	24.3 a
	- Spray	114.4 a	73.2 a	62.4 a	23.1 a
		Secondary bud			
No Salinity	+ Spray	166.3 a	88.4 a	74.4 a	31.8 a
	- Spray	166.0 a	87.4 a	74.3 a	31.5 a
Salinity only	+ Spray	108.2 a	70.7 a	63.7 a	20.6 a
	- Spray	113.5 a	70.3 a	63.0 a	21.4 a
Salinity + Ca	+ Spray	123.9 a	74.9 a	69.1 a	23.9 a
	- Spray	123.6 a	74.7 a	67.8 a	23.2 a
Salinity + Bacillus	+ Spray	128.1 a	78.4 a	70.4 a	24.6 a
	- Spray	121.1 a	77.5 a	69.3 a	23.2 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

Appendix 4: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on soil electrical conductivity and Cl and Na contents in the soil of artichoke plant 2 to 12 weeks after treatments start

Interaction treatments		2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A	Factor B						
		Electrical conductivity [EC, dS m^{-1}] in the 1:10 soil:water extract					
No Salinity	+ Spray	0.28 a	0.32 a	0.35 a	0.36 a	0.35 a	0.38 a
	- Spray	0.27 a	0.31 a	0.37 a	0.37 a	0.34 a	0.34 a
Salinity only	+ Spray	0.62 a	1.14 a	0.71 a	0.76 a	0.61 a	0.60 a
	- Spray	0.62 a	1.13 a	0.72 a	0.73 a	0.59 a	0.58 a
Salinity + Ca	+ Spray	0.60 a	1.01 a	0.69 a	0.70 a	0.60 a	0.61 a
	- Spray	0.59 a	0.89 a	0.67 a	0.66 a	0.60 a	0.60 a
Salinity + Bacillus	+ Spray	0.58 a	0.85 a	0.64 a	0.58 a	0.56 a	0.52 a
	- Spray	0.57 a	0.81 a	0.69 a	0.61 a	0.58 a	0.54 a
		Cl content in the soil [mg kg^{-1}]					
No Salinity	+ Spray	40.0 a	37.7 d	39.7 e	35.0 a	36.7 a	34.7 d
	- Spray	43.0 a	33.3 d	38.3 e	37.0 a	35.3 a	31.3 d
Salinity only	+ Spray	919.7 a	1346.0 b	625.0 bc	770.7 a	657.3 a	676.7 b
	- Spray	972.0 a	1962.3 a	781.7 a	808.3 a	729.3 a	736.0 a
Salinity + Ca	+ Spray	1072.7 a	1152.0 bc	660.0 b	641.0 a	555.7 a	638.0 b
	- Spray	1212.0 a	1207.0 bc	654.0 b	590.7 a	552.7 a	507.3 c
Salinity + Bacillus	+ Spray	771.3 a	976.0 c	509.0 d	451.3 a	405.3 a	506.7 c
	- Spray	836.3 a	721.7 c	577.0 c	552.0 a	438.0 a	625.3 b
		Na content in the soil [mg kg^{-1}]					
No Salinity	+ Spray	173.3 a	156.0 e	186.7 f	159.3 e	167.7 f	167.0 a
	- Spray	250.0 a	145.7 e	157.3 f	157.3 e	167.0 f	166.3 a
Salinity only	+ Spray	917.3 a	974.7 b	645.0 e	889.3 b	862.7 a	987.7 a
	- Spray	950.3 a	1445.3 a	877.3 a	1026.0 a	877.0 a	1127.7 a
Salinity + Ca	+ Spray	923.3 a	809.3 cd	844.3 b	673.0 c	642.3 b	719.0 a
	- Spray	964.0 a	844.0 c	671.3 e	626.0 c	575.0 c	762.3 a
Salinity + Bacillus	+ Spray	880.0 a	963.7 b	730.7 d	565.7 d	458.0 e	794.7 a
	- Spray	835.3 a	716.0 d	778.0 c	656.0 c	500.0 d	712.0 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

Appendix 5: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on K and Ca contents of soil of artichoke plants

Interaction treatments		2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Factor A	Factor B						
		K content in the soil [mg kg^{-1}]					
No Salinity	+ Spray	70.0 a	102.0 a	80.0 a	74.3 a	56.7 a	44.7 d
	- Spray	56.0 a	115.3 a	71.0 a	73.3 a	60.7 a	41.3 d
Salinity only	+ Spray	46.0 a	78.3 a	67.0 a	52.3 a	64.0 a	38.3 d
	- Spray	49.0 a	86.7 a	69.7 a	60.7 a	65.7 a	47.3 cd
Salinity + Ca	+ Spray	56.0 a	109.3 a	118.7 a	56.7 a	98.3 a	50.7 c
	- Spray	64.0 a	113.7 a	100.3 a	56.0 a	91.0 a	57.3 c
Salinity + Bacillus	+ Spray	51.7 a	132.0 a	158.7 a	103.3 a	95.7 a	87.0 a
	- Spray	76.0 a	132.3 a	134.3 a	114.3 a	98.0 a	72.3 b
		Ca content in the soil [mg kg^{-1}]					
No Salinity	+ Spray	135.7 a	108.3 a	132.3 a	124.0 a	172.3 a	129.3 a
	- Spray	127.3 a	123.7 a	110.3 a	131.3 a	173.3 a	106.3 a
Salinity only	+ Spray	126.0 a	78.0 a	96.0 a	104.3 a	138.0 b	106.0 a
	- Spray	122.7 a	70.0 a	116.3 a	99.0 a	135.7 b	102.3 a
Salinity + Ca	+ Spray	130.3 a	85.0 a	101.0 a	107.0 a	134.0 b	112.7 a
	- Spray	124.3 a	82.0 a	102.0 a	126.0 a	139.0 b	117.7 a
Salinity + Bacillus	+ Spray	126.7 a	78.0 a	100.7 a	118.7 a	135.3 b	110.3 a
	- Spray	129.3 a	97.3 a	93.3 a	100.7 a	127.7 b	114.7 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

Appendix 6: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on Cl and Na contents in the different parts of artichoke plants

Interaction treatments		4^{th}-leaf at each 2 weeks			Edible part		Shoots	Roots
Factor A	Factor B	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
		Cl content in plant [% DW]						
No Salinity	+ Spray	1.02 a	0.85 a	1.02 a	0.45 a	0.51 a	1.10 d	0.49 d
	- Spray	1.02 a	0.86 a	0.90 a	0.49 a	0.53 a	0.86 d	0.45 d
Salinity only	+ Spray	3.57 a	4.26 a	3.13 a	1.31 a	1.41 a	5.73 a	0.68 a
	- Spray	4.19 a	4.17 a	3.12 a	1.35 a	1.65 a	5.06 b	0.61 b
Salinity + Ca	+ Spray	2.97 a	4.62 a	3.16 a	1.33 a	1.66 a	5.20 b	0.58 bc
	- Spray	3.33 a	4.19 a	2.79 a	1.22 a	1.77 a	5.23 b	0.65 ab
Salinity + Bacillus	+ Spray	3.41 a	4.03 a	2.64 a	1.30 a	1.59 a	5.24 b	0.54 c
	- Spray	3.27 a	3.65 a	2.69 a	1.54 a	1.45 a	4.03 c	0.56 bc
		Na content in plant [% DW]						
No Salinity	+ Spray	0.74 c	0.69 a	0.60 a	0.36 a	0.19 d	1.23 e	0.45 a
	- Spray	0.97 c	0.73 a	0.29 a	0.36 a	0.19 d	0.96 e	0.36 a
Salinity only	+ Spray	2.70 b	3.78 a	2.13 a	0.55 a	0.69 b	5.16 a	0.63 a
	- Spray	3.48 a	3.29 a	2.13 a	0.57 a	0.87 a	4.44 b	0.50 a
Salinity + Ca	+ Spray	2.59 b	3.09 a	1.76 a	0.40 a	0.83 a	3.94 c	0.51 a
	- Spray	2.58 b	3.03 a	1.64 a	0.29 a	0.70 b	3.74 c	0.45 a
Salinity + Bacillus	+ Spray	3.27 a	3.05 a	1.82 a	0.33 a	0.68 b	4.39 b	0.49 a
	- Spray	3.04 ab	2.76 a	1.51 a	0.35 a	0.56 c	3.18 d	0.45 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

Appendix 7: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on K, Ca and Mg contents in the different parts of artichoke plants

Interaction treatments		4^{th}-leaf at each 2 weeks			Edible part		Shoots	Roots
Factor A	Factor B	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
		K content in plant [% DW]						
No Salinity	+ Spray	3.23 a	3.49 a	3.38 a	4.32 a	3.41 a	3.89 a	0.82 a
	- Spray	3.08 a	3.57 a	3.47 a	4.86 a	3.39 a	3.29 a	0.79 a
Salinity only	+ Spray	3.56 a	3.02 a	3.05 a	3.54 a	3.08 a	3.92 a	0.83 a
	- Spray	3.39 a	2.91 a	2.68 a	3.05 a	3.41 a	3.18 a	0.81 a
Salinity + Ca	+ Spray	3.16 a	2.82 a	3.86 a	3.47 a	3.68 a	3.77 a	0.90 a
	- Spray	3.52 a	2.96 a	3.98 a	3.46 a	3.59 a	4.37 a	0.88 a
Salinity + Bacillus	+ Spray	3.58 a	4.09 a	4.46 a	3.99 a	4.09 a	4.05 a	0.94 a
	- Spray	3.31 a	3.52 a	3.70 a	3.71 a	3.78 a	4.12 a	0.92 a
		Ca content in plant [% DW]						
No Salinity	+ Spray	1.21 a	1.37 a	0.93 a	0.36 a	0.20 a	2.06 a	0.42 a
	- Spray	1.47 a	1.27 a	0.80 a	0.22 bc	0.20 a	1.60 a	0.35 a
Salinity only	+ Spray	1.08 a	1.13 a	0.65 a	0.19 bc	0.16 a	1.24 a	0.27 a
	- Spray	0.92 a	0.92 a	0.69 a	0.18 c	0.16 a	1.20 a	0.25 a
Salinity + Ca	+ Spray	1.28 a	1.39 a	0.92 a	0.25 b	0.17 a	1.75 a	0.29 a
	- Spray	1.38 a	1.21 a	0.65 a	0.22 bc	0.17 a	1.83 a	0.29 a
Salinity + Bacillus	+ Spray	1.28 a	1.21 a	0.70 a	0.23 bc	0.16 a	1.55 a	0.17 a
	- Spray	1.22 a	1.15 a	0.66 a	0.22 bc	0.15 a	1.34 a	0.19 a
		Mg content in plant [% DW]						
No Salinity	+ Spray	0.32 a	0.30 a	0.23 a	0.30 a	0.20 a	0.45 a	0.19 a
	- Spray	0.30 a	0.28 a	0.20 a	0.26 b	0.21 a	0.39 a	0.11 a
Salinity only	+ Spray	0.21 a	0.18 a	0.17 a	0.19 d	0.13 b	0.30 a	0.11 a
	- Spray	0.22 a	0.16 a	0.18 a	0.17 de	0.15 b	0.25 a	0.09 a
Salinity + Ca	+ Spray	0.20 a	0.19 a	0.18 a	0.15 e	0.21 a	0.28 a	0.10 a
	- Spray	0.25 a	0.20 a	0.16 a	0.13 f	0.14 b	0.26 a	0.11 a
Salinity + Bacillus	+ Spray	0.30 a	0.22 a	0.20 a	0.22 c	0.14 b	0.38 a	0.12 a
	- Spray	0.26 a	0.19 a	0.18 a	0.15 e	0.14 b	0.25 a	0.11 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

Appendix 8: Interaction effect between EC of nutrient solution and additive of Ca or *Bacillus subtilis* (Factor A) and spraying of mixture of Fe, Mn and Zn compared to no spraying (Factor B) on Fe, Mn and Zn contents in the different parts of artichoke plants

Interaction treatments		4^{th}-leaf at each 2 weeks			Edible part		Shoots	Roots
Factor A	Factor B	2 weeks	4 weeks	6 weeks	Main	Secondary	12 weeks	
		Fe content in plant [mg kg^{-1} DW]						
No Salinity	+ Spray	83.0 a	56.0 a	115.0 a	60.3 a	44.3 a	129.0 a	192.0 a
	- Spray	38.0 a	42.3 a	89.3 a	50.3 a	43.7 a	83.0 a	117.3 bc
Salinity only	+ Spray	64.0 a	52.3 a	84.0 a	37.7 a	35.7 a	144.0 a	131.0 b
	- Spray	39.0 a	45.3 a	43.3 a	38.7 a	40.0 a	91.7 a	88.0 c
Salinity + Ca	+ Spray	60.7 a	39.3 a	100.3 a	36.3 a	46.0 a	151.7 a	81.0 c
	- Spray	52.0 a	47.3 a	50.3 a	30.7 a	38.7 a	122.0 a	98.3 bc
Salinity + Bacillus	+ Spray	72.0 a	65.3 a	96.7 a	34.0 a	38.0 a	184.7 a	103.0 bc
	- Spray	44.0 a	38.0 a	57.3 a	31.0 a	41.3 a	99.3 a	95.3 bc
		Mn content in plant [mg kg^{-1} DW]						
No Salinity	+ Spray	276.0 a	213.7 a	441.0 a	41.0 a	19.7 a	403.3 a	48.7 a
	- Spray	32.0 a	26.3 a	35.7 a	24.3 a	14.7 a	129.3 a	35.0 a
Salinity only	+ Spray	319.0 a	228.3 a	335.0 a	36.0 a	22.3 a	436.7 a	32.3 a
	- Spray	36.3 a	40.0 a	53.0 a	26.3 a	19.7 a	79.3 a	18.7 a
Salinity + Ca	+ Spray	253.0 a	169.7 a	256.3 a	45.3 a	31.0 a	356.3 a	35.0 a
	- Spray	36.3 a	35.7 a	33.7 a	29.3 a	18.7 a	71.3 a	16.3 a
Salinity + Bacillus	+ Spray	216.3 a	207.0 a	407.3 a	54.0 a	22.7 a	355.3 a	26.0 a
	- Spray	30.7 a	37.7 a	46.3 a	38.7 a	18.7 a	79.0 a	19.7 a
		Zn content in plant [mg kg^{-1} DW]						
No Salinity	+ Spray	267.0 a	232.0 a	361.7 a	53.7 a	126.0 a	428.7 a	92.3 a
	- Spray	40.3 a	73.0 a	98.3 a	39.0 a	94.7 a	156.0 a	49.3 a
Salinity only	+ Spray	174.7 a	160.0 a	310.0 a	49.3 a	89.0 a	391.3 a	59.7 a
	- Spray	44.0 a	66.7 a	116.0 a	45.7 a	68.0 a	124.3 a	46.0 a
Salinity + Ca	+ Spray	247.3 a	194.7 a	288.7 a	66.0 a	61.7 a	318.3 a	71.7 a
	- Spray	67.7 a	76.7 a	128.3 a	48.7 a	69.3 a	125.3 a	53.7 a
Salinity + Bacillus	+ Spray	261.0 a	253.7 a	323.3 a	71.0 a	74.7 a	466.7 a	70.0 a
	- Spray	91.3 a	81.7 a	84.7 a	36.7 a	61.3 a	121.3 a	66.3 a

Means within each column and measurement followed by the same letter are not significantly different at $P<5\%$

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