EFFECTS OF ISTANBUL METROPOLITAN MUNICIPALITY COMPOST PRODUCT ON PLANT GROWTH, MINERAL NUTRIENTS AND HEAVY METALS IN PLANT AND SOIL

by
AYDA ONAT

Submitted to the Graduate School of Engineering and Natural Sciences
in partial fulfillment of
the requirements for the degree of
Master of Science

SABANCI UNIVERSITY
July 2008

EFFECTS OF ISTANBUL METROPOLITAN MUNICIPALITY COMPOST PRODUCT ON PLANT GROWTH, MINERAL NUTRIENTS AND HEAVY METALS IN PLANT AND SOIL

APPROVED BY:

Assoc. Prof. Dr. Levent Öztürk (Thesis advisor) ....

Prof. Dr. İsmail Çakmak (Thesis co-advisor) ....

Prof. Dr. Selim Çetiner ....

Prof. Dr. Yuda Yürüm ....

Assoc. Prof. Dr. Uğur Sezerman ....

Prof. Dr. Hayriye İbrikçi ....

DATE OF APPROVAL: ...15.07.2008...

EFFECTS OF ISTANBUL METROPOLITAN MUNICIPALITY COMPOST PRODUCT ON PLANT GROWTH, MINERAL NUTRIENTS AND HEAVY METALS IN PLANT AND SOIL

Ayda Onat
Biological Sciences and Bioengineering, Master Thesis, 2008
Thesis Advisor: Assoc. Prof. Levent Öztürk
Thesis Co-advisor: Prof. İsmail Çakmak

Key words: MSW compost, plant nutrition, zeolite, boron toxicity, zinc deficiency, salt toxicity, biomass production, micronutrient

Abstract

Large scale municipal solid waste (MSW) production is a common environmental problem in metropolitan areas of the world. Converting the organic fraction of MSW obtained from residential areas into environmentally acceptable products is possible through composting process. Composting of MSW is widely accepted as an environmentally friendly and sustainable solution for recycling large amounts of MSW collected by metropolitan municipalities. The final product "compost" can be further utilized in agriculture, horticulture, landscaping, erosion control, reclamation and landfill applications.

In this study, the compost product of Istanbul metropolitan municipality was characterized to reveal its potential on plant growth and mineral nutrition. The two common problems of MSW composts, heavy metals and high salt content, were also assessed by greenhouse pot experiments using different plant species. In a series of incubation experiments, the long term effects of compost amendments to soil was tested to understand the changes in plant nutrient concentrations, nutrient bioavailability and levels of salt and heavy metal accumulation in soils.

Chemical analysis performed on the compost product showed that it is rich in organic matter (i.e. %46) and various plant macro and micro nutrients. Although not comparable to strict EU legislation for eco-compost, concentrations of heavy metals were similar or even lower than typical MSW composts. In greenhouse experiments compost applications to soil up to 5% (w/w) promoted plant growth, particularly at low productivity conditions with limited basal fertilizer rates. Using soils with inherent problems such as zinc (Zn) deficiency and boron toxicity, it was demonstrated that compost applications can totally eliminate Zn deficiency and decrease accumulation of B to safer limits in plant shoots. However, higher application rates resulted in occurrence of salt toxicity symptoms which could be alleviated to a certain extent by the use of zeolite amended compost during processing. Shoot concentration of heavy metals, particularly Cd and Pb, were also increased at higher application rates.

It was concluded that MSW compost produced by Istanbul metropolitan municipality can be beneficial in agricultural production with some limitations. Although it was shown to enhance plant biomass production particularly at low productivity and Zn deficient conditions, there is the need for on-site and long-term field trials to acquire cost-benefit relations and ensure safe heavy metal limits in harvested plant parts.

İSTANBUL BÜYÜK ŞEHİR BELEDİYESİ KOMPOST ÜRÜNÜNÜN BİTKİ BÜYÜMESİNE, BİTKİDEKİ VE TOPRAKTAKİ MİNERAL BESİNLERE VE AĞIR METALLERE ETKİSİ

Ayda Onat
Biyoloji Bilimleri ve Biyomühendislik, Yüksek Lisans Tezi, 2008
Tez Danışmanı: Doç. Levent Öztürk
Tez Yardımcı Danışmanı: Prof. İsmail Çakmak

Anahtar kelimeler: Kentsel atık kompostu, bitki beslenmesi, zeolit, bor toksisitesi, çinko eksikliği, tuz toksisitesi, biyokütle üretimi, mikrobesin

Özet

Büyük ölçekli kentsel katı atık üretimi dünyanın büyük kentlerinde ortak olan çevresel bir problemdir. Yerleşim bölgelerinden toplanan kentsel katı atıkların organik kısımlarının çevre ile uyumlu ürünlere dönüştürülmesi kompostlaştırma işlemiyle mümkündür. Kentsel katı atıkların kompostlaştırılması, büyük şehir belediyeleri tarafından toplanan büyük miktardaki bu atıkların geri dönüşümü açısından çevreyle dost ve sürdürülebilir bir çözüm olarak geniş ölçüde kabul görmektedir. Son ürün olan "kompost" ayrıca tarımcılık, bahçecilik, peyzaj, erozyon kontrolü, toprak ıslah etme, ve toprak doldurma uygulamalarında kullanılabilir. Bu çalışmada, İstanbul büyük şehir belediyesinin kompost ürünü bitki büyüme ve mineral beslenmesine etkisini göstermesi açısından karakterize edildi. Kentsel katı atık kompostlarının iki yaygın problemi olan ağır metal ve yüksek tuz muhtevası da sera saksı denemeleriyle farklı bitkiler kullanılarak değerlendirildi. Seri halde yapılan inkübasyon denemeleriyle bitki besin konsantrasyonu, besin alınabilirliği ve topraktaki tuz ve ağır metal birikim düzeyi değişimlerini anyalabilmek için kompost katkısının uzun dönemde toprağa etkileri test edildi.

Kompost ürününde gerçekleştirilen kimyasal analizler bu ürünün organik maddece (%46) ve çeşitli bitki makro ve mikro besinlerince zengin olduğunu gösterdi. Eko-kompost için yapılan katı Avrupa Birliği yasasıyla karşılaştırılabilir olmamasına karşın, ağır metal konsantrasyonları tipik kentsel atık kompost değerlerine benzer hatta daha düşük çıkmıştır. Sera denemelerinde toprağa ağırlıkça %5e kadar olan kompost uygulamaları bitki büyümesini, özellikle temel gübre oranının sınırlı olduğu düşük verimlilik durumlarında desteklemiştir. Doğasında çinko (Zn) eksikliği ve bor (B) toksisitesi gibi problemleri olan topraklar kullanılarak kompost uygulamalarının bitki yeşil aksamında Zn eksikliğini tamamen giderdiği ve B birikimini güvenilir değerlere düşürdüğü gösterilmiştir. Fakat, yüksek uygulama oranları, kompostlaştırma işlemi sırasında zeolit katkılı kompost kullanımı ile belli boyutta azaltılabilen, tuz toksisite simptomlarının ortaya çıkması ile sonuçlanmıştır. Özellikle Cd ve Pb olmak üzere yeşil aksam ağır metal konsantrasyonları da yüksek uygulama dozlarıyla artmıştır.

İstanbul büyük şehir belediyesi tarafından üretilen kompostun bazı sınırlamalarla tarımsal üretimde yararlı olabileceği düşünülmektedir. Bitki biyokütlesinin özellikle düşük verimlilikte ve Zn eksikliği durumlarında geliştiği gösterilmiş olmasına rağmen, maliyet-kar ilişkileri elde etmek ve hasat edilen bitki kısımlarının ağır metal sınırlarını kesinleştirmek için yerinde ve uzun vadeli tarla denemelerine ihtiyaç vardır.

“TO MY FAMILY...”

ACKNOWLEDGEMENTS

This thesis could not have been written without the contribution of these people in assorted ways. It is a plesure to convey my gratitude to them.

In the first place, I would like to express my gratitude to Assoc. Prof. Levent Öztürk not only for his supervision, but also for his guidance in every stage of the study and his kind approach to the diffuculties. I am much indebted to my co-advisor Prof. İsmail Çakmak for giving me a chance to benefit from his extraordinary experiences. I owe my growth in science as a student to these two people. They have indespensible place in my life.

I am greatful to faculty members, Prof. Selim Çetiner, Prof. Zehra Sayers, Assoc. Prof. Hikmet Budak, Assoc. Prof. Uğur Sezerman who always spent time for answering my questions with their kindness. I am also thankful to Prof. Yuda Yürüm and Prof. Hayriye İbrikçi for her participation to my presentation and spending time.

My special thanks go to my friends Burcu Saner, Özge Özdemir, Emel Yeşil, Ebru Kaymak, Simin Ataç, Alper Küçükural, Sinem Yılmaz, Gizem Karslı, Ferah Gülaçtı, Ümit Barış Kutman, Nurşah Peker, Didem Ağaç and Direnç Dalgıç. I can not imagine these years without their friendships. I would like to acknowledge Atilla Yazıcı Veli Bayır, Uğur Atalay, Özay Özgür Gökmen, Yusuf Tutuş and Esen Andiç for maintaining a friendly environment in the laboratories and for their support. In many times, we worked together like a team. I will never forget their help.

I wish to specially thank Oğuz Orallar for his support and understanding who listened my studies and ideas about the experiments everytime patiently unless he did not understand anything about the project.

I would like to express my greatest gratitude to my mother, my brother, and my grandmother for their greatest encouragements and motivation to carry out my research work, and my father. I hope he is aware of my success. It is a pleasure for me to dedicate this thesis to them.

This thesis was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under project no. 105G0148, “Use of organic wastes of Istanbul Metropolitan as compost in agricultural production”. Finally, I would like to acknowledge TÜBİTAK for financial support.

TABLE OF CONTENTS

TABLE OF ABBREVIATIONS

AI: Agricultural index

Al: Aluminum

B: Boron

C: Carbon

Ca: Calcium

$CaCl_2$: Calcium chloride

Cd: Cadmium

CEC: Cation exchange capacity

Cl: Chlorine

Cu: Copper

DAP: Days after planting

DTPA: Diethylene triamine pentaacetic acid

DW: Dry weight

EC: Electrical conductivity

Fe: Iron

h: hour

HNO_3: Nitric acid

H_2O_2: Hydrogen peroxide

IBB: Istanbul Metropolitan Municipality

ICP-OES: Inductively coupled plasma optical emission spectroscopy

K: Potassium

kg: Kilogram

µg: Microgram

M-III: Mehlich 3

mg: Milligram

Mg: Magnesium

min: Minute

Mn: Manganese

Mo: Molybdenum

mm: millimeter

N: Nitrogen

Na: Sodium

Ni: Nickel

P: Phosphorus

Pb: Lead

PTE: Potential toxic elements

S: Sulphur

TEA: Triethanolamine

Zn: Zinc

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Waste is defined as any substance or object that the producer wants to get rid of. Municipal solid waste is generally defined as the type of waste consisting mainly household and commercial wastes (Williams, 1998).

As the population increases, the use of consumable products increases as well resulting in production of huge amounts of municipal solid waste (MSW). The produced MSW should be properly treated and decomposed under controlled environments to prevent any hygiene related problems that would negatively affect human life. Municipal solid waste is mainly composed of kitchen and yard waste (Otten, 2001). Composting of MSW is widely accepted as the most advantageous solution for disposal. Composting of MSW is an economic, efficient and sustainable solution when compared to other disposal methods such as landfill or incineration (Barreira *et al*., 2007). Composting process mainly involves the microbial decomposition of organic fraction of MSW. Depending on the product quality, compost can be further used in agriculture, horticulture, landscaping, erosion control or land cover. (Eriksen *et al*., 1999).

Briefly, composting can be defined as the biological decomposition of organic materials under aerobic conditions. More specifically, it is a controlled biological process in which organic fraction of waste is decomposed in a moist, warm, and aerobic environment by a mixed microbial population into carbon dioxide, water, minerals, and stabilized organic material (Renkow and Rubin, 1998). Composting can be carried out under either natural or controlled conditions. Under controlled conditions, firstly, large particles are broken down to smaller particles by grinding and chopping. When optimal physical conditions are reached, bacteria, fungi, and protozoa colonize the organic material and initiate composting process (Figure 1.1). These mesophilic organisms function best at 10-45°C. As composting proceeds, temperature in the pile rapidly increases to 55-65°C within 24-72 hours and thermophiles start functioning. This “active phase” of composting takes place for several weeks. At this temperature, pathogens like *Escherichia coli, Staphylococcus aureus, Bacillus subtillus*, and *Clostridium botulinum* and phytotoxic compounds (organic compounds toxic to plants) are degraded (Cooperband, 2002). Total number of the population of coliforms, especially *Streptococci*, *Staphylococci*, *Salmonella*, and *Shigella* decreased at the thermophilic stage (Hassen *et al*., 2001).

As the composting process decelerates, temperature gradually downs to around 37°C. The mesophilic microorganisms recolonize the pile, and the compost enters the "curing phase". During this phase, organic materials continue to decompose and are converted to biologically stable humic substances. In order to have a mature and finished product, the length of curing phase is significant (Cooperband, 2002; Figure 1.1).

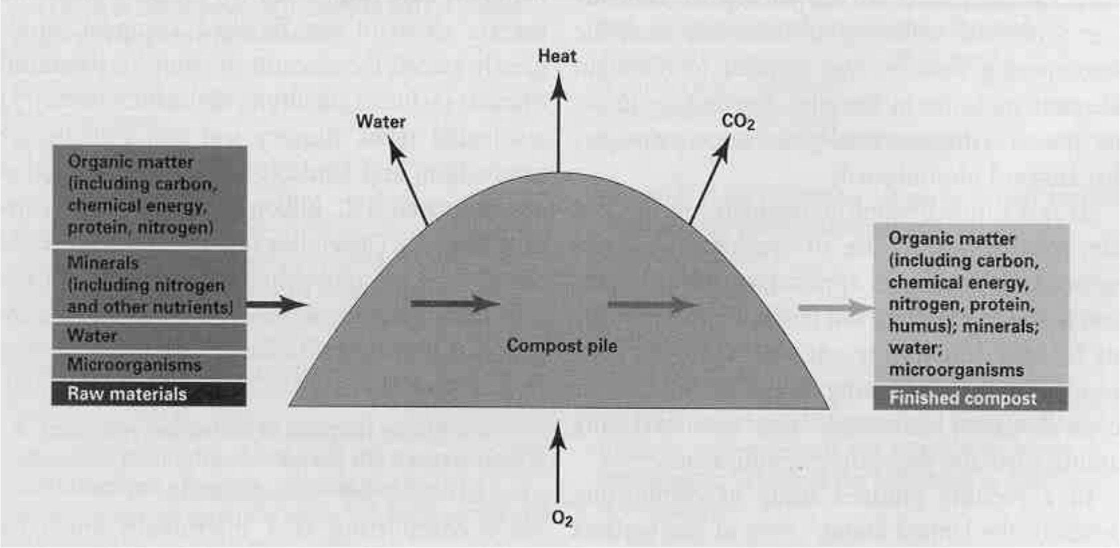


Figure 2.1.1 Schematic presentation of composting process (Rynk, 1992).

Composting process has been an important treatment for recycling of biodegradable wastes in developed countries since many years. Large-scale municipal composting in Europe was first initiated in Holland in 1929 by the Dutch Government (Gray and Biddlestone, 1980). It took about 40 years for Europe to respond this attempt and during 1970s intensive large-scale composting of MSW was adopted in many European countries (de Bertoldi, 1999). Mechanical and biological treatment plants (MBT) have been used at those times. In the MBT process, organic matter fraction was mechanically separated from MSW before the biological composting process. Since hammer mills, shredders and drums were used to reduce the particle size of the feedstock, the compost product included glass and plastics. Moreover, as a result of household products, compost had high concentrations of heavy metals. These problems lead to poor compost quality. In 1990s, with strict changes in legislations and environmental standards, new composting facilities have emerged. As a result, source separated organic waste composting has been developed (Gruneklee, 1997). DHV (1997) reported that, of 60 million metric tons of potentially recoverable organic waste produced in the EU; France produces 24%; Germany, Italy and the UK 15% each; Spain 11%; Austria 4%; Belgium, Greece and the Netherlands 3% each; Sweden and Portugal 2% each, and Denmark, Finland and Ireland each contribute 1%. Nearly 15% of the recoverable organic fraction has been recovered through composting. According to a survey study conducted in 1999, 833,000 tons of municipal and non-municipal waste was composted in UK (Slater and Frederickson, 2001).

There are various technologies and different systems for composting MSW. Most systems include separation, metal removal, shredding, and water addition before composting. Additional processes of removing unwanted materials may be done after composting. The quality of the final compost product highly depends on processing activities (Epstein *et al.*, 1992).

Stabilization of organic matter in MSW is essential since untreated organic matter in MSW can potentially result in environmental pollution (Lima *et al.*, 2004). During composting process, while carbon dioxide and water are released into the atmosphere, organic matter and minerals are converted into a stable organic-rich, soil like material called compost. The volume of the feedstock is reduced by nearly 25-60% with the loss of carbon dioxide and water (Renkow and Rubin, 1998). Therefore, composting minimizes the environmental problems related to the management of wastes by reducing the volume of waste and eradicating bacterial pathogens (Sabo and Ferrini, 2006). Besides other benefits to the community and the environment, it also contributes to economical development of countries (Lima *et al.*, 2004).

In Istanbul metropolitan area, approximately 8,600 tons of municipal solid waste is produced daily and about 5% of this amount is processed in the Kısırmandıra composting plant producing 200 tons of finished compost product daily (Altinbas *et al.*, 2007). The composting plant is constructed in three main units; material recovery facility, fermentation facility and the physical post process area (Figure 1.2). Initial separation of MSW starts at the conveyor belts with 80 mm holes. The undersized materials are collected and fed to the tunnel type eight-stage (one week for each stage) fermentation unit. At the end of each stage, the decomposing materials are transferred to the next stage by mixing and re-watering. Fermentation process lasts for about 50-60 days. During fermentation process with the action of thermophilic bacterial activity the pile temperature rises above 55°C for over 20 days. During this phase, water is added to the pile to provide a moisture content of 35-60%. At the last stage, moisture content is reduced to 25-30% to recover fine compost by 15 mm rotary sieve (Altinbas *et al.*, 2007).

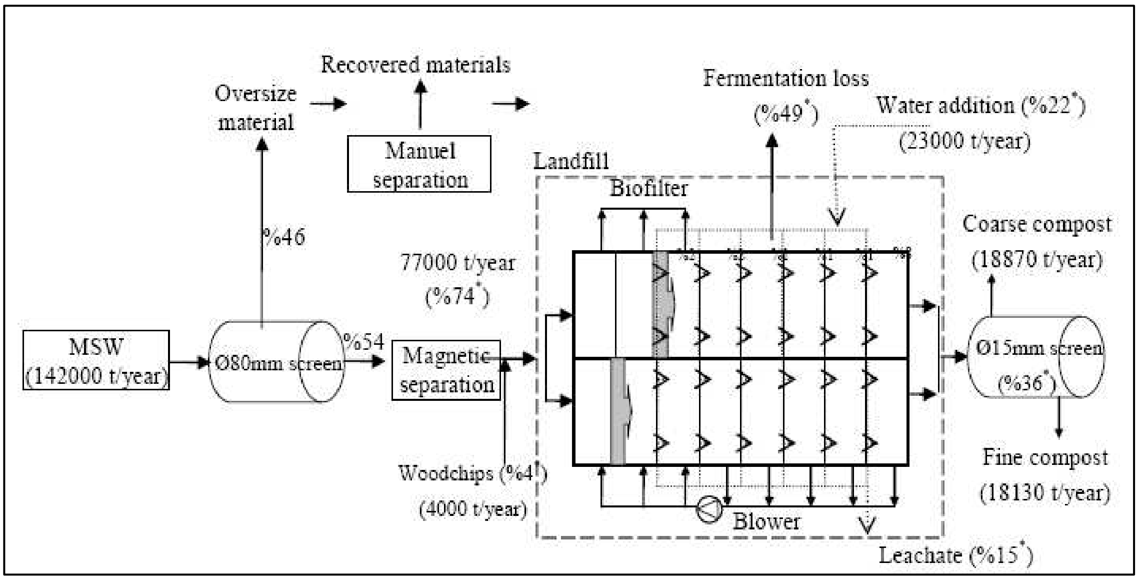


Figure 2.1.2 Schematic presentation of composting process at İ.B.B. Kısırmandıra Composting Plant located in Kemerburgaz, İstanbul (Altinbas *et al.*, 2007)

Compost can be used as a soil conditioner and fertilizer in a variety of agricultural, horticultural or landscaping applications. The volume reductions of the waste with composting process and possible uses of compost as a soil amendment make composting attractive. However, finished product may contain undesirable materials such as glass, metal and plastic. These materials should be absent or in very small quantities to obtain high quality compost (Renkov and Rubin, 1998).

MSW compost show significant physical, chemical and biological differences according to the feedstock composition, composting procedure, length of maturation period, and materials used in the composting plant. Along with these differences, effect of compost applications may differ significantly depending on the type of soil, agricultural management strategies and plant species in question (Hargreaves *et al.*, 2008).

In traditional composting, various kinds of agricultural byproducts (straw, livestock manure, poultry litter, lawn clippings etc.) is used as raw material. This type of compost has usually good quality with low content of potentially toxic substances (i.e. organic pollutants and heavy metals). However, various other organic sources are increasingly being used for compost production since last decade (Gomez, 1998):

- Compost obtained from food and agricultural wastes is rich in organic matter since it is not mixed with other impurities.
- Compost obtained from town horticultural waste (park and garden) generally has high metal content because of the pollution by town activities.
- Compost may be derived from tree bark, sawdust, and wood chip. This kind of compost has high C:N ratio. Therefore, it is applied to soil with manure or sewage sludge addition. However, addition of sewage sludge increases the heavy metal content of the soil.
- Sewage sludge is used with wood waste. The reason of the use of wood waste is to dilute heavy metal concentration found in sewage sludge.
- Household refuse is the common compost type used in the world nowadays. The quality of the finished product depends on the quality of the materials found in household refuse.

These wastes can be mixed to produce different kinds of composts. Municipal solid waste which is mainly composed of household and commercial wastes goes through composting process and as a final product MSW compost is produced (Gomez, 1998).

MSW compost can be used in a variety of areas; it is used as a potting medium for container crops grown in greenhouses and nurseries, as soil amendment for field nursery and sod production, turf and highway greens establishment, landscaping, homeowner gardens, agronomic and horticulture crop production, silviculture, remediation of contaminated sites and landfill cover (Cooperband, 2000).

According to a survey study conducted in Illinois (USA), greenhouses, sport turf operations and landscape contractors were found to be the most likely purchasers of compost. The primary reasons for compost use were reported to be related to soil improvement; enhancing humus content of the soil and increasing plant growth, where as replacement of chemical fertilizer use was not supporting the main reason of compost use (Walker *et al*., 2006).

Urban green areas are generally poor in quality because of having little aeration and drainage, having low amount of organic material, etc. Such problematic issues make cultivation difficult in these areas (Urban, 1998). Application of high-quality compost enhances soil conditions by improving the physical and chemical soil characteristics and affecting the biological processes that take place in the soil (Obreza *et al*., 1989). Yard waste composts are mainly derived from green wastes from gardens and parks. Amlinger *et al*. (2003) stated that yard waste composts supply nutrients, organic matter and also beneficial micro-organisms to the soil. These micro-organisms are important for nutrient recycling and good health of plants by competition with other harmful pathogens in the soil (Dumontet *et al*., 1999; Fichner *et al*., 2004).

In this thesis study we investigated the suitability of the compost product of Istanbul Metropolitan Municipality for agricultural production. For this purpose greenhouse pot experiments were conducted with grass, wheat, maize, and lettuce species using increasing rates of compost and basal fertilizer treatments. Plant growth responses and mineral nutrient status were determined as affected by compost and fertilizer treatments. The two common problems of MSW compost; high heavy metal and salt content were also investigated by soil and plant analysis. In all pot experiments, potentially toxic heavy metals were analyzed in plant shoots. A separate soil incubation experiment was conducted to monitor the changes in extractable amount of mineral nutrients and heavy metals in the soil as affected by increasing rates of compost applications and duration of time.

2 OVERVIEW

2.1 Compost Quality

Compost may be produced from both non-source separated and source separated wastes called “bio-waste” which means that all organic fractions of the waste are collected separately. Figure 2.1.1 shows the development of the use of source separated compost in Europe.

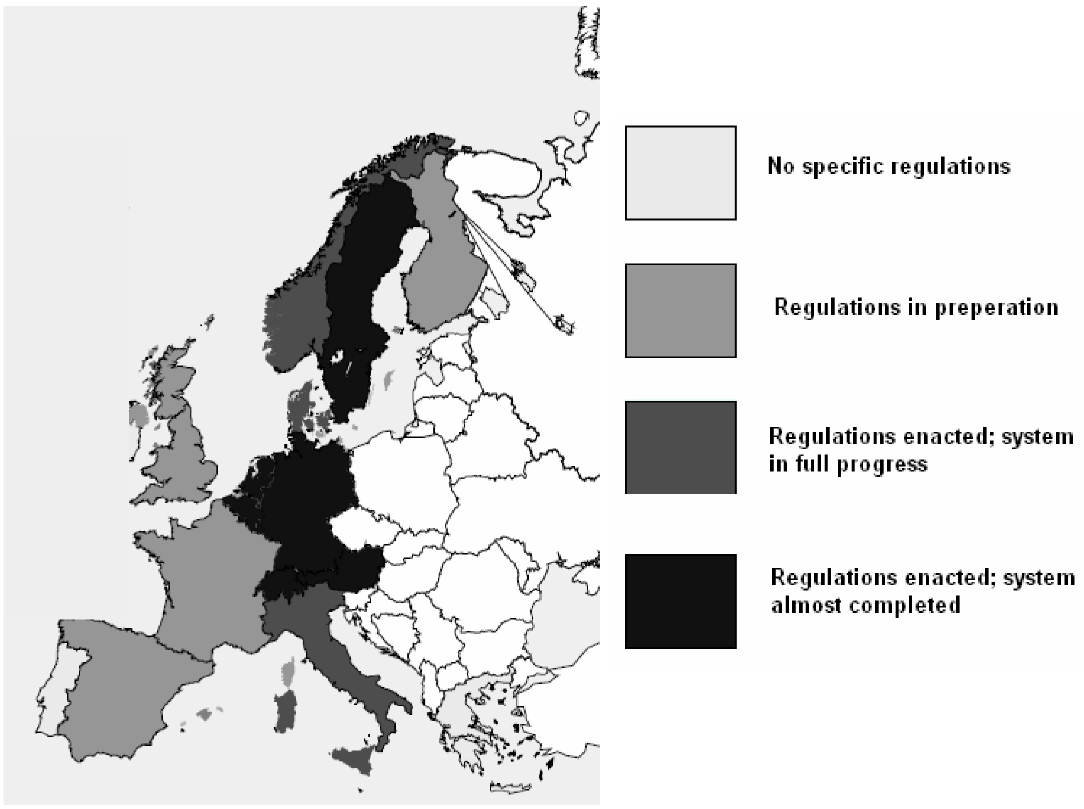


Figure 2.1.1 The use of source separated compost in Europe (Amlinger et al., 2004).

Compost has been used for many years in many areas of the world, but issues concerning compost quality has not emerged before 1990s (OMRI, 1998).

The quality of compost and its suitability for agricultural application depend on compost physical and chemical properties such as water holding capacity, porosity, pH, electrical conductivity, C:N ratio, nutrient concentration and the absence of toxic substances (Silva *et al*., 2007). Compost maturity is a critical parameter since immature composts may contain high levels of organic acids, high C:N ratio, high pH values, and high salt contents leading to reduced plant growth poor soil quality. Immature or biologically unstable composts can be applied to soils only if planting takes place several months after compost addition (Cooperband, 2002).

There are many chemical and biological analyses that identify compost quality. Most important ones include heavy metal content, pH, C:N ratio, organic matter content, and salinity. Some studies and discussions about these parameters are given below.

2.1.1 Heavy Metal Concentration

Trace elements are found in both naturally occurring materials (yard wastes, food wastes) and manmade materials (plastics, metals). Discarded materials, such as plastics, metal objects, pigments, solvents, paper, wood products, glass, and petroleum products are found as feedstock of compost product, and therefore it is impossible to have a compost product without trace elements. The removal of many manmade materials from the municipal solid wastes at composting facilities prior to composting process can reduce the levels of trace elements in MSW composts (Epstein *et al*., 1992).

The level of trace elements often referred to as heavy metals in MSW compost may be a health concern when it is applied to soils where plants are grown. Toxic trace elements are generally referred as heavy metals which are classified by the density of the elemental state (i.e. >5 g cm^{-3}). Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn) are the main trace elements that are in concern (U. S. Environmental Protection Agency, 1989). Boron (B), molybdenum (Mo), and selenium (Se) are also other elements which may be of concern to human health (Epstein et al., 1992).

Heavy metal content of compost has been the main focus among other potential quality standards (Brinton, 2000). European countries and United States have established standard values for metal ranges in compost where these values may significantly differ among countries. In Tables 2.1.1 and 2.1.2, different limit values for potential toxic elements (PTE) in compost is given for EU countries and legislations including the results from a survey study. As judged from the data in Table 2.1.1, there is a substantial variation among EU countries, often exceeding the average of accepted limit values. Accordingly, none of the survey composts (produced from mixed MSW) could meet the limit values for organic farming in EU (Table 2.1.1). There also exists proposed limit values for PTEs in which soil texture is considered. The reason for this is that bioavailability of PTEs is highly influenced by adsorption/desorption and cation exchange capacity (CEC) of soils (Amlinger et al., 2004).

Table 2.1.1 Limit values of potential toxic elements (PTE) for mixed municipal solid waste compost in EU: average limit values of EU countries, limit values for composts allowed to be used in organic farming in EU, proposed limit values for soils having different texture and average concentration of PTEs derived from EU national compost survey (Amlinger et al., 2004).

		Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
		(mg kg^{-1} DW)							
Limit values of EU countries	avarage	1.4	93	143	1.0	47	121	416	23
Limits for organic farming	2092/91 EC- 1488/98 EC	0.7	70	70	0.4	25	45	200	--
Proposed limit values	clay	1.63	107.01	70.08	1.10	75.94	107.63	260.57	--
	loam/silt	1.10	64.41	48.78	0.56	54.64	75.68	207.32	--
	sand	0.46	32.46	27.48	0.14	17.36	43.73	111.47	--
EU National Compost Survey	range of concentrations	1.7 – 5.0	70 – 209	114 – 522	1.3 – 2.4	30 – 149	181 – 720	283 – 1,570	12.7

The limit PTE values set by the the “Soil Polution Control Regulations” (TKKY) of Türkiye is among the highest when compared to EU countries and legislations (Table 2.1.2). The TKKY limits are 40 (i.e. for Cd) to 8 (i.e. for Ni) fold higher than the EU legislation 2001/688/EC. Limits of PTEs in compost are generally stricter in countries such as Austria, Germany, Netherlands, Belgium and Sweden, where as Greece, Portugal, Spain and France impose higher limits (Table 2.1.2). The TKKY limits proposed for soil organic amendments are closest to Spain and Portugal, however these limits were set for sewage sludge and practically should not be considered for compost products (Table 2.1.2).

Table 2.1.2 Heavy metal compost limits for municipal solid waste composts where compost production and application are regulated by law. (Hogg *et al*., 2002; TKKY, 2005).

Country	Regulation	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
					(mg kg^{-1} KM)				
Austria	Compost Ordinance: Quality Class A+ (organic farming)	0.7	70	70	0.4	25	45	200	–
	Compost Ordinance: Quality Class A (agric.; hobby gardening	1	70	150	0.7	60	120	500	–
	Compost Ordinance: Quality Class B (landscaping; reclaim.) li	3	250	500	3	100	200	1800	–
	Compost Ordinance: Quality Class B (landscaping; reclaim.) g	–	–	400	–	–	–	1200	–
Belgium	Ministry of Agriculture	1.5	70	90	1	20	120	300	–
Denmark	Compost after 01 06 2000	0.4	–	1000	0.8	30	60	4000	25
Finland	Fertilised growing media	3	–	600	2	100	150	1500	50
France	NF Compost Urbain	3		–	8	200	800	–	–
Germany	Quality assurance RAL GZ – compost/digestion	1.5	100	100	1	50	150	400	–
	Bio waste ordinance (I)°	1	70	70	0.7	35	100	300	–
	Bio waste ordinance (II)°	1.5	100	100	1	50	150	400	–
Greece	Specifications framework and general programmes for solid w	10	510	500	5	200	500	2000	15
Ireland	Limits in recent licences	1.5	100	100	1	50	150	350	15
Italy	Limit values for solid organic fraction	10	500	600	10	200	500	2500	10
	Green (ACV) and MIXED13 (ACM) Composted Amendment	1.5	–	150	1.5	50	140	500	–
Luxembourg	Licensing for plants	1.5	100	100	1	50	150	400	–
Netherlands	Compost	1	50	60	0.3	20	100	200	15
	Compost (very clean)	0.7	50	25	0.2	10	65	75	5
Portugal	Decree on sludge (limit values utilised also for MSW)	20	1000	1000	16	300	750	2500	–
Spain	Decr.1310/1990 pH>7 (sewage sludge in agriculture)	40	1500	1750	25	400	1200	4000	–
	Decr.1310/1990 pH<7 (sewage sludge in agriculture)	20	1000	1000	16	300	750	2500	–
	Order 28/V/1998 on fertiliser B.O.E.n'm.131.2 June 1998	10	400	450	7	120	300	1100	–
Spanish draft on comp	Class AA	2	250	300	2	100	150	400	–
	Class A (Stabilised Biowaste)	5	400	450	5	120	300	1100	–
Catalunya draft on cor	Class A	2	100	100	1	60	150	400	–
	Class B (Stabilised Biowaste)	3	250	500	3	100	300	1000	–
Sweden	Guideline values of QAS	1	100	100	1	50	100	300	–
UK	UKROFS 'Composted household waste'	0.7	70	70	0.4	25	45	200	–
	Composting Association Quality Label	1.5	100	200	1	50	150	400	–
Canada	BNQ Types AA and A, CCME Category A	3	210	100	0.8	62	150	500	13
	BNQ Type B, CCME Category B and AAFC	20	1060	757	5	180	500	1850	75
USA	EPA CFR40/503 Sludge Rule	39	–	1500	17	420	300	2800	41
	NY State DEC* Class I	10	100	1000	10	200	250	2500	–
	WA State Dept of Ecology, Grade A	10	600	750	8	210	150	1400	20
	WA State Dept of Ecology, Grade AA	39	1200	1500	17	420	300	2800	20
	Texas TNRCC Grade 1 Compost	16	180	1020	11	160	300	2190	10
	Texas TNRCC Grade 2 Compost	39	1200	1500	17	420	300	2800	41
	Rodale Organic Seal of Compost Quality	4	100	300	0.5	50	150	400	10
Australia	ARMCANZ limits for biosolids	3	400	200	1	60	200	250	20
New Zealand	DoH Values (1992)	15	1000	1000	10	200	600	2000	–
EC	Draft W.D. Biological Treatment of Biowaste (class 1)	0.7	100	100	0.5	50	100	200	–
	Draft W.D. Biological Treatment of Biowaste (class 2)	1.5	150	150	1	75	150	400	–
	2001/688/ EC	1	100	100	1	50	100	300	10
	2092/91 EC- 1488/98 EC	0.7	70	70	0.4	25	45	200	–
Türkiye	TKKY*	40	1200	1750	25	400	1200	4000	–

Various studies investigated the applicability of MSW compost considering the PTE concentration. According to a study conducted in Spain, characterization of industrial MSW compost (MSWC) compared with the quality of other composted biowaste and conventional substrates such as peat and pine bark. The MSWC was obtained from one of the main composting facilities in Spain. According to the analysis, it was found that MSWC and other compost products presented similar available nutrient concentrations. With respect to the heavy metal concentrations, Zn and Cu concentrations in MSWC exceeded the limits proposed by the Spanish regulation of compost (Silva et al., 2007).

Epstein et al. (1992) reported that heavy metal concentrations in mixed MSW compost was lower than the levels found is sewage sludge and sludge compost. Although heavy metal concentrations in source separated MSW compost of EU were found to be much lower than the mixed MSW compost of US, heavy metal concentrations in mixed MSW compost were found within the ranges of U.S. EPA and did not comprise a significant risk to human health or the environment (Epstein et al., 1992). Kraus and Grammel (1992) examined compost samples taken from seven different regions which were paired into either MSW-based compost or source-separated (bio-waste) compost. They found that MSW compost contained nearly four fold total heavy metals than the bio-waste composts (Kraus and Grammel, 1992). Similar data have been indicated by many other researchers (Wiemer and Kern, 1989).

Compared to typical MSW compost, the PTEs in İSTAÇ A.Ş. compost product can be considered in normal ranges (Table 2.1.3). According to preliminary PTE analysis conducted during 2006-2007, only B and Cu values were found to be higher than MSW composts of USA, France, Holland or Canada. However, the PTE values of İSTAÇ A.Ş. compost are quite higher than the limits set by EU legislations and EU countries with strict regulations (Table 2.1.2 and 2.1.3).

Table 2.1.3 Concentrations of PTEs in MSW composts produced in USA, France, Holland, Canada and İSTAÇ A.Ş. (He et al., 1995; He et al., 1992; Zheljazkov and Warman, 2004).

Element	USA[1]	USA[2]	France	Holland	Canada[3]	İSTAÇ[4]
			$(\mathrm{mg\ kg^{-1}})$			
B	60.9	-	60	60	-	71
Cd	3.3	3.5	7	6	3	1.3
Cr	76	72.4	270	220	210	127
Cu	281	212.5	250	630	100	343
Co	-	-	-	-	34	9
Hg	-	2.4	4	5	0.8	0.7
Mn	501	-	600	400	-	427
Ni	34	36.2	190	110	62	68
Pb	234	235.5	600	900	150	131
Zn	655	582.8	1000	1650	500	618

USA[1]: average value of composts taken from 5 different state municipalities
USA[2]: average value of composts produced from 5 different private compost plants
Canada[3]: heavy metal limits of compost for agricultural use according to Canada environmental ministry
ISTAC[4]: average value of composts produced from İSTAÇ A.Ş. between July 2006 – October 2007

Land application of MSW compost is generally restricted due to PTEs (i.e. Cd, Pb, Hg, As, Se) that exceed the proposed limits. Zeolites are known to be good metal stabilizers with exceptionally high cation exchange capacity (CEC). Previously, studies were conducted to assess the effects of zeolite addition on leachability and bioavailability of PTEs in the composts (Angelidis and Gibbs, 1988; Rudd et al., 1988; Brennan, 1991; Garcia-Delgado et al., 1994; Zorpas et al., 2000). Recently, it was demonstrated that addition of 20-25% (w/w) natural zeolite (clinoptilolite) to the compost pile during composting can effectively stabilize PTEs (i.e. 100% of Cd, 28-45% of Cu, 10-15% of Cr, 41-47% of Fe, 9-24% of Mn, 50-55% of Ni and Pb, and 40-46% of Zn) (Zorpas *et al*., 2000).

2.1.2 Humic Substances

Besides pollutants like heavy metals, organic pollutants and impurities and organic matter content is considered to be a quality parameter for compost. Since humic acid concentration represents a stable fraction of organic matter, humic acid is an important parameter for determination of compost maturation (Meissl *et al*., 2008). Humic acid is generally considered to be more stable than fulvic acid and its addition to soil increases the buffering capacity of the soil (He *et al*., 1995; Garcia-Gil *et al*. 2004). Binner *et al*. studied humic acid fraction of 132 different compost samples taken from different composting processes. According to the results, composting systems were found to be important in order to obtain composts having high humic acid fraction. Aerated windrow systems and reactor systems were found to be suitable systems for high quality compost. Furthermore, the period of the active phase of composting was reported to be necessary. A long lasting biological reactivity for humic acid formation was needed (Binner *et al*., 2008).

2.1.3 C:N Ratio

High-quality compost is often described using expressions such as “mature” or “stable” compost. Many authors suggest that C:N ratio may be a good indicator of compost stability (Goyal *et al*., 2005). During composting process, carbon compounds are metabolized and mineralized by various microorganisms and nitrogen content decreases mainly because of ammonia volatilization. In spite of ammonia volatilization, with the activity of nitrogen fixing bacteria, a small amount of nitrogen recovery is possible. However, in terms of dry weight an increase in nitrogen is only evident due to the mineralization of organic matter. Accordingly, a decrease in C:N ratio is observed throughout the process (de Bertoldi *et al.*, 1982)

An optimum C:N ratio indicates that there are enough nutrients in the medium. For stable compost, C:N ratio should be between 15 and 20. If the C:N ratio is higher than 20, microorganisms will deplete the N for their own needs and if it is lower than 15, an excess N occurs and it is converted to ammonia which cause odor problems (Epstein, 1997; Bar-Tal et al., 2004; Pickering and Shepherd, 2000). Therefore, a high C:N ratio may lead to nitrogen immobilization; where as composts having low C:N ratio may result in ammonia toxicity.

2.1.4 pH

The pH of the plant growth medium is highly significant for availability of plant nutrients. In general, pH decreases during the early stages of composting and then increases slightly up to 6.5-7.5 (Esptein, 1997). When MSW composts reach to maturity, pH is usually found to be neutral or slightly alkaline, mainly because of the break down of organic acids during maturation of compost. Pickering and Shepherd (2000) pointed out that effect of compost on soil pH would be less than expected in many instances. Because, buffering capacity of composts may be quite low if the amount of calcium is low leading to a poor effect on soil pH. On the contrary, a high Ca and $CaCO_3$ pool will increase buffering capacity. Application of composts having high amounts of Ca to acidic soils leads to a rise in soil pH (Sabo and Ferrini, 2006).

2.1.5 Salt Content

Plants are negatively affected by excess soluble salt. Electrical conductivity (EC) of compost:water solution (usually 1:5 w/v) is generally used for a measure of total soluble salt content of composts (Brady and Weil, 1996). The EC of MSW compost is mainly related to the feedstock and composting facility procedures (Hicklenton *et al.*, 2001). He *et al.* made a survey of selected MSW composts and EC of the composts were found to be much higher than that of agricultural soils and their agricultural application may restrain seed germination (He *et al.*, 1995). It was pointed out that EC levels of agricultural soils range from 0 to 4 dS m^{-1} whereas MSW composts ranged from 3.7 to 7.5 dS m^{-1} (Brady and Weil, 1996). Many studies concluded that Na concentrations in MSW composts range from 3.5 to 21.0 g Na kg^{-1} (He *et al.*, 1995; Warman and Rodd, 1998; Garcia-Gil *et al.*, 2000; Warman, 2001; Warman *et al.*, 2004). Since plants species have different sensitivities to salt stress, compost applications to soil should be done cautiously. In 2000, Australia government has set standards to compost applications based on EC value of compost (Table 2.1.4; Brinton, 2000).

Table 2.1.4 Maximum compost application rates based on salt content (Brinton, 2000).

EC of Compost	rate for sensitive plants	rate for tolerant plants
	liters / m^2	
0-1	unlimited	unlimited
1-2	< 15	< 60
2-4	< 8	< 32
4-8	< 4	< 16
8-12	< 2.5	< 10
>12	< 2	< 8

Agricultural index is another standard for the determination of salinity in compost products. It was proposed by TMECC (Test Methods for the Examination of Composting and Compost) and calculates salt index by the ratio of macro nutrients N, P and K to Na and Cl. Compost with an agricultural index below two is suggested to cause salt injury to susceptible crops. Composts with an agricultural index between two and five is suggested to be applied to soils with low soluble salt content by using good quality irrigation water, where as composts having AgIndex between five and ten can be applied to all soils including high amount of total soluble salts (TMECC, 2001).

$$\textbf{Agricultural Index} = [N_{total} + P_2O_5 + K_2O] / [Na + Cl_2]$$

TMECC (AgIndex: AI)			
1	2 3 4 5	6 7 8 9 10	>10
salt injury probable	applicable on soils with excellent drainagle characteristics, good water quality and low salts	applicable on soils with poor drainage, poor water quality or high salts	for all soils

Figure 2.1.2 Determination of salinity in composts using the Agricultural Index (TMECC, 2001).

2.2 Effects of Compost on Soil Properties

2.2.1 Physical Properties

Compost is a unique substance that improves chemical, physical, and biological characteristics of soils. Soil organic matter (SOM) is an important parameter for soil quality. Physical, chemical and biological characteristics of soil are dependent on SOM content. Tillage, agricultural activities, climate, temperature, and military activities can alter SOM content (Brady, 1990). It has several beneficial effects on soil structure and contributes to the stabilization of soil particles, therefore decreasing erosion risk. With balanced SOM content soil physical properties such as structure, aeration, water penetration and water holding capacity improves drastically. The gradual decrease in the SOM content causes a degradation of soil physical conditions and favors erosion risk (Deiana *et al*., 1990; Giusquiani *et al*., 1992; Martens *et al*., 1992). The organic matter content of MSW compost is high and its agricultural application improves soil physical and chemical properties and enhances soil biological activity (Shiralipour *et al*., 1992). According to a survey, on average, 20% of the total C in MSW compost is in organic form, whereas 8% is carbonate C and 71% is residual C which may have had organic C components (He *et al*., 1995).

Humic acids are bio-organic molecules that have molecular mass smaller than 1000 Da (Dalton) (Piccolo, 2002). Therefore, its increase in soil improves the soil structure making a better medium for plant roots to penetrate. It improves soil texture and permeability to air and water. With improved root growth, nutritional status increases and water stress decreases (Stuckey and Hudak, 2001).

The compost produced from MSW is generally stable, disinfected and high in organic matter with high nutrient availability for plants. As a soil conditioner, MSW compost enhances various soil physical properties such as water retention, soil structure, porosity, and bulk density, thus making the soil a more valuable medium for plant growth (Epstein *et al*., 1976). Application of MSW compost increases the storage pores, improves pore size distribution, and consequently increases the water holding capacity (Pagliai *et al*., 1981). Soil bulk density can also decrease with compost applications (Mays *et. al*., 1973). Decrease in soil bulk density is suggested to be due to low particle density of MSW compost and tendency of particles to increase soil total pore space (Pagliai *et al*., 1981; May *et al*., 1989). Among the impacts of compost to soil physical properties, it is also known that application of MSW compost enhances soil aggregate stability in relation to the formation of cationic bridges (Hernando *et al*., 1989; Annabi *et al*., 2007).

2.2.2 Chemical Properties

Most MSW composts have neutral or slightly alkaline pH. Application of MSW compost to acidic soils increases the pH of the soil and reduces Al and Mn toxicity related to low pH (Hernando *et al*., 1989; Mays *et al*., 1973; Mays *et al*., 1989). On the contrary, MSW compost application to alkaline calcareous soils causes a slight decrease in pH (Hortenstine and Rothwell, 1973; King *et al*., 1977).

Electrical conductivity of soil solution indicates the dissolved solutes content of soil and is often used to measure soil salinity. Many authors stated that Na concentrations in MSW composts ranged from 3.50 to 21.0 g Na kg^{-1} (He *et al*., 1995; Warman and Rodd, 1998; Garcia-Gill *et al*., 2000; Warman 2001; Warman *et al*. 2004). In most of the MSW compost studies, application of compost increased soil EC level. Electrical conductivity of soil shows an increase with the increase in loading rate of compost. The reason of the increase of soil EC values with compost application is caused by extensive decomposition of organic materials leading to high salt concentrations (Manios and Syminis, 1988). Zhang et. al. reported that the increase in soil EC values caused by compost application declined over time. The decline may have been due to the nutrient removal by crops and leaching (Zhang *et al*., 2006).

Compost application has an effect on soil cation exchange capacity (CEC). According to many reports, low loading rates of compost did not have significant effect on CEC while high loading rates caused increase in CEC (Mays *et al*., 1989). It was suggested that as a result of increased CEC of soils by compost applications, fertilizer requirements can be reduced by 50% (Cooperband, 2002).

Available macro element status of the soil is important for plant growth. However, soils are generally poor in available N, P, K, S concentrations. Nitrogen is a fundamental element of amino acids and proteins and therefore plant growth is dramatically affected by N fertilization (Wilkinson, 2000). In general compost applications increase total soil N content. However, when compared with inorganic mineral N fertilizers, MSW compost supplies less phytoavailable N in the first year of application (Iglesias-Jimenez and Alvarez, 1993; Warman and Rodd, 1998; Eriksen *et al.*, 1999). In the case of K, it was observed that about 36-48% of the total K in MSW compost was plant available (deHaan, 1981; Soumare *et al.*, 2003) and even very low levels of compost applications could increase soil K concentrations (Giusquiani *et al.*, 1988). Various studies have demonstrated that application MSW compost to soil can result in concomitant increases in soil Ca, S, and Mg concentrations as well (Maynard, 1995; Warman *et al.*, 2004; Zhang *et al.*, 2006).

Application of MSW compost caused an increase in total soil Mn concentrations (Giusquiani *et al.*, 1988; Murphy and Warman, 2001). However, most of the total Mn in soil was found to be in the iron and manganese oxide (FeMnOX) form which is unavailable to plants (Zheljazkov and Warman, 2004). It was stated that MSW compost application to acidic soils usually decreased plant Mn availability due to increase in pH (Warman *et al*, 2004). Gallardo-Lara *et al.* (2006) indicated that following compost application, Mn concentration was increased in lettuce, but decreased in barley when plants were grown in MSW compost treated calcareous soil.

It has been reported that total and extractable Cu concentrations showed an increase in soils treated with MSW compost (Warman *et al.*, 2004; Zheljazkov and Warman, 2004; Zhang *et al.*, 2006). Other researchers suggested that, low rates of compost applications did not affect plant available Cu in the soil, however Cu was increased mostly in the unavailable forms (Giusquiani et al., 1988; Zheljazkov and Warman, 2004). As a possible explanation to this it was concluded that while the exchangeable Cu was increased, Cu bioavailability was reduced due to complexation with organic ligands in the applied compost (Hernando *et al.*, 1989; Zheljazkov and Warman, 2004).

Many studies point out that total soil Zn concentration increases with MSW compost additions when compared to unamended controls (Giusquiani *et al.*, 1988; Pinamonti *et al.*, 1999; Walter *et al.*, 2006; Zhang *et al.*, 2006). There are also reports confirming an enhanced Zn bioavailability to plants as a result of compost applications to soil (Hernando *et al.*, 1989; Pinamonti *et al.*, 1999).

In the literature there are contradictory results on the effect of the MSW compost treatment to soil and plant Fe concentrations. While it was reported that that MSW compost application to a sandy loam soil had no significant effect on available soil Fe and plant uptake, other researchers claimed that available soil Fe can significantly increase with increasing compost application rates (Maftoun *et al*., 2004; Warman *et al*., 2004).

Boron in MSW compost was found to be highly extractable with water and KCl. High rates of compost applications may therefore cause B phytotoxicity resulting from high mobility of this element (He *et al*., 1995). However, in the case of B deficient soils, this may help improving B nutrition of crops (He *et al*., 1995).

In contrast to various benefits of compost on soil, there are also drawbacks such as heavy metals and other potential toxic elements, particularly in composts produced from non-source separated MSW. Depending on the quality, composts may contain elevated levels of trace elements which in turn would negatively effect the environment and human life (Epstein, 1997). In order to minimize any negative effect of compost on the environment, many countries have established standards and regulations about compost products and their application areas. These regulations commonly include limits for potentially toxic organic and inorganic constituents of compost products (Hogg *et al*., 2002; TKKY, 2005). Trace elements are not only found in compost, but also available in the environment. All soils contain measurable amounts of trace elements including heavy metals with different concentrations based on mainly the composition of parent material on which the soil is formed (Sommers *et al*., 1987). Many soil properties such as pH, organic matter, iron and aluminum oxides and phosphorus affect the bioavailability of trace elements (Sommers *et al*., 1987). Moreover, agricultural practices such as fertilization and pesticide use contribute to the amount of heavy metals found in the soil (Epstein *et al*., 1992). High amounts of compost applications may increase the natural levels of heavy metals in soil leading to environmental pollution with heavy metals. In various studies, it was found that soil total Pb increased with MSW compost applications (Pinamonti *et al*., 1999; Sebastiao *et al*., 2000; Walter *et al*., 2006). The increase in soil Ni, Cd, and Cu levels were seen by Pinamonti *et al*., 1999 (Pinamonti *et al*., 1999). In fact, the metal bioavailability caused by MSW compost addition to the soil depends on the compost maturity and the quality related to the feedstock sources, composting process and the duration of the composting process (He *et al*., 1992). Humic substances, which are capable of binding the metals in the compost product, increase with compost maturity and therefore decrease metal bioavailability (Deportes *et al*., 1995). So, application of such compost on soil may not increase soil metal bioavailability.

2.2.3 Biological Properties

Application of MSW compost effects soil biological properties, as well. Bhattacharyya et. al. observed that application of 2.5, 5, 10, 20, 40 t ha^{-1} MSW compost increased soil microbial C and soil respiration, which is the basic method for determining total soil biological activity (Bhattacharyya *et al.*, 2003a). Giusquiani et al. reported that MSW compost application to soil enhanced some enzymatic activities, such as L-asparaginase, arylsulphatase, dehydrogenase, phosphodiesterase, and phosphomonoesterase. The increased levels of arylsulphatase, dehydrogenase, phosphodiesterase and phosphomonoesterase were supposed to be related to the increase in total porosity caused by compost addition (Giusquiani *et al.*, 1995). It was also reported that the enzyme activities of β-glucosidase and nitrate reductase increased with different rates of compost applications (Crecchio *et al.* 2001). On the contrary, total protease and urease activities were found to decrease with MSW compost applications. The decrease, in both cases, was suggested to be due to the toxic effects of heavy metals in the applied compost product (Garcia-Gil *et al.*, 2000).

It is well-known that compost application makes soil microbially active (Pascual *et al.*, 2002). High-quality compost has high fraction of humic acids. The increase in the humic acid content of soils provided by compost amendments may result in various beneficial effects in soil biological processes (Obreza *et al.*, 1989). A good example to this would be that humic substances found in the soil suppress pathogens (Pascual *et al.*, 2002) by enhancing microbial activity against soil-borne and foliar pathogens while accelerating the breakdown of pesticides and other synthetic organic compounds (Cooperband, 2002).

2.3 Effects of Compost on Plants

Compost applications can influence plant health and productivity both positively and negatively depending on the quality of the compost product and application rate. Compost maturity and composition of feedstock material are the main factors determining compost quality and thus application rates. An application of high doses of immature compost or non-separated MSW compost may lead to significant problems related to phytotoxicity. In contrast, application of an appropriate dose of good quality compost enhances soil fertility and plant productivity. Therefore, management strategies should both include composting process and agricultural practices.

2.3.1 Crop Yield

Many authors proved that the yield of agronomic crops increase when plants were grown on compost treated soils (Kuo *et al.*, 2004). According to a study, addition of 25 t ha^{-1} of MSW compost increased the yield of ryegrass when compared to untreated plots (Bauduin *et al.*, 1987). In a similar study, 8, 16, 32, and 64 t ha^{-1} MSW compost were applied to a sandy soil and it was observed that the heights and dry weights of sorghum crops increased with compost applications. Compared to NPK fertilizers sorghum yield was found to be equal or slightly higher in the case of 64 t ha^{-1} of MSW compost application (Hortenstine *et al.*, 1973). The grain yield of maize, durum wheat, Italian ryegrass, and sorghum were increased by 10-25% by different rates of composts applications to soil (Paris *et al.*, 1987). Effect of increasing rates of separated and non-separated Brazilian MSW composts were tested for corn biomass production, stem height and diameter. Although corn growth was enhanced by both type of MSW composts, biomass production and other growth parameters were found higher for separated MSW compost. Appropriate dose of non-selected compost application for corn production was found to be 15 t ha^{-1} (Lima *et al.*, 2004).

The yield of potatoes, sweet corn, ryegrass and barley were reported to be lesser in MSW compost treated soils compared to fertilizer treatments (Iglesias-Jimenez and Alvarez, 1993; Warman and Rodd, 1998; Rodd *et al.*, 2002; Mkhabela and Warman, 2005). Iglesias-Jimenez and Alvarez suggested that this poor effectiveness in plant yield occurred because of N immobilization caused by increased soil microbial biomass (Iglesias-Jimenez and Alvarez, 1993). Application of MSW compost with N fertilization often provided better yields than MSW compost alone (Shiralipour *et al.*, 1992). In a greenhouse experiment using silt-loam soil, sorghum shoot biomass was demonstrated to increased with increasing compost application rates. Similarly, the highest yield was obtained when compost and N fertilizer were used in combination (Terman *et al.*, 1973).

2.3.2 Mineral Nutrition and Heavy Metal Accumulation

Many researches point out that compost affects the bioavailability and leaching of nutrients in the soil (Shiralipour *et al.*, 1992). Eghball et al. and Whalen and Chang observed that organic matter application to soil increased P bioavailability (Eghball *et al.*, 1996; Whalen and Chang, 2001). There are many studies conducted with various plant species (e.g. strawberries, tomatoes, spinach, ryegrass, potatoes, Swiss chard) to investigate the changes in P uptake upon compost treatment. All of these studies pointed out the same result concluding that the plant uptake of P increased with increasing compost application rates (Iglesias-Jimenez *et al.*, 1993; Warman, 2001; Maftoun *et al.*, 2004; Mkhabela and Warman, 2005; Zheljazkov and Warman, 2004; Shanmugam 2005).

MSW compost has also shown to be a good source of K for plants. Plants grown in soils treated with MSW compost had higher K concentrations than untreated controls (Warman *et al*, 2004; Rodd *et al.*, 2002). Although MSW compost was reported to be a good Ca source, there are studies in which plant uptake of Ca did not show significant difference with compost application (Warman *et al.*, 2004; Zheljazkov and Warman, 2004). In terms of S, it was observed that MSW compost application caused firstly a decrease and then an elevation in S uptake of ryegrass grown in calcareous soil (Nogales *et al.*, 1985). Moreover, there are various studies showing the positive effect of compost on S uptake (Hargreaves *et al.*, 2007). Magnesium is another macronutrient element which shows increases in plant tissue with compost treatment (Hargreaves *et al.*, 2007). In summary, data from literature clearly supports the existence of a positive effect of MSW compost on plant macro nutrient uptake and bioavailability indicating that compost has a fertilizer effect on crop plants.

A potential restraint in agricultural application of MSW compost may be due to existence of elevated levels of heavy metals. Various studies have been conducted to investigate the uptake of metals from composts by different species including wheat (*Triticum aestivum L.*), corn (*Zea mays L.*), oat (*Avena sativa L.*), soybean (*Glycine max L.*), lettuce (*Lactuca sativa L.*), Swiss chard (*Beta vulgaris L.*), Chinese cabbage (*Brassica chinensis L.*) and basil (*Ocimum basilicum L.*) (Sims and Kline, 1991; Henry and Harrison, 1992; Gigliotti *et al.*, 1996; Wong *et al.*, 1996; Pichte and Anderson, 1997; Simeoni *et al.*, 1984; Warman *et al.*, 1995; Zubillaga *et al.*, 2002). As one would expect, in all these independent studies composts with different characteristics and application rates were tested. The common result of the studies was the increase in Cd, Cu, Ni, and Zn concentrations in plant parts (e.g., shoots, grains, straw etc) with the increase in compost application rates.

Copper and Zn are reported to be the most common metals that may cause potential risk for both environment and plants when compost application rates are too high (Epstein 1997; Bhattacharyya *et al*., 2004). Bhattacharyya *et. al.* focused on the effect of MSW compost on Cu and Zn in rice at a rate of 6 t compost ha^{-1} for three consecutive years. Finally it was concluded that uptake of Cu and Zn was within safe limits (Bhattacharyya *et al*., 2006).

In lettuce Fe concentration was slightly decreased at 20 t ha^{-1} MSW compost, but increased significantly when supplied with 80 t ha^{-1} MSW compost in a calcareous soil (Gallardo-Lara *et al*., 2006).

In a study conducted in Brazil, amendment of clayey soil with MSW compost increased lettuce yield and shoot Cu, Mn, Ni, Pb, and Zn concentrations when applied at a rate of 35 or 70 t ha^{-1}. However, none of the metals exceed the maximum limits allowed by the Brazilian legislation (Claudio, 2007).

Many trace elements (Cu, Zn, Se, Mo, Ni, Cr, and B) are essential to plants. It is difficult to determine exact levels of essentiality for plant uptake since the essentiality or toxicity often varies depending on the plant species (EPA, 1989). There are many studies about the uptake of trace elements from various types of composts. Uptake shows significant differences among species, as well as cultivars within species. Furthermore, accumulation differs in different plant organs. Generally, trace element concentration is found to be more in leaves than roots, grains and fruits (Esptein, 1997). With compost application, Cd and Zn concentrations in lettuce were found to be much higher than in oats when grown in the same environmental conditions (Simeoni *et al*., 1984).

Therefore, the metal composition and rate of MSW compost should be taken into consideration together before any agricultural application. High dosages of compost application to soil may lead to phytotoxicity problems and growth rate suppression. Most pronounced problems have been high soluble salts, heavy metal toxicity and B toxicity which may be detrimental to plants (Sanderson, 1980; Lumis and Johnson, 1982; Conover and Joiner 1966; Chu and Wong, 1987).

3 MATERIALS AND METHODS

3.1 Materials

3.1.1 Seed Material

Lettuce (*Lactuca sativa* cv. Lital 300) and grass (*Festuca rubra* and *Lolium perenne*) seeds were bought from a commercial supplier whereas durum wheat seeds (*T. durum* cv. Kümbet 2000) were provided from Anatolian Agricultural Research Institute.

3.1.2 Soil Material

The calcareous soils used in the experiments were transported from two locations in Central Anatolia, Eskisehir-Sultanönü and Konya-Çomaklı. Both soils had a clayey loam texture with inherently low levels of plant available Zn (i.e. DTPA-Zn) concentration, particularly Eskisehir-Sultanönü soil. Besides Zn deficiency, the soil from Konya-Çomaklı had also toxic levels of B. Both soils were air dried and passed through a 2-mm sieve before potting. Some basic characteristics of Zn-deficient (Eskisehir-Sultanönü) and B-toxic (Konya-Çomaklı) soils used in the greenhouse pot experiments are provided in Table 3.1.1.

Table 3.1.1 Some basic characteristics of Zn-deficient (Eskisehir-Sultanönü) and B-Toxic (Konya-Çomaklı) soils used in the greenhouse pot experiments.

Parameter	Zn-Deficient Soil	B-Toxic Soil
pH	8.1 ± 0.4	8.2 ± 0.5
EC	130 ± 1	321 ± 17
Total C (%)	1.8 ± 0.1	6.9 ± 0.3
C/N	10 ± 0.4	23 ± 1.1
DTPA Na (mg kg^{-1})	5.7 ± 1.3	135 ± 9
DTPA Fe (mg kg^{-1})	2.7 ± 0.2	1.9 ± 0.1
DTPA Mn (mg kg^{-1})	12 ± 1	11 ± 0
DTPA Cu (mg kg^{-1})	1.04 ± 0.03	0.21 ± 0.01
DTPA Zn (mg kg^{-1})	0.08 ± 0.02	0.11 ± 0.03
DTPA B (mg kg^{-1})	0.16 ± 0.02	12.25 ± 0.92
DTPA Cd (µg kg^{-1})	18.0 ± 1.0	4.1 ± 0.1
DTPA Co (µg kg^{-1})	93 ± 8	58 ± 3
DTPA Cr (µg kg^{-1})	0.77 ± 0.32	1.06 ± 0.65
DTPA Mo (µg kg^{-1})	2.1 ± 0.7	16.0 ± 1.9
DTPA Ni (µg kg^{-1})	2253 ± 70	499 ± 21
DTPA Pb (µg kg^{-1})	840 ± 46	309 ± 16
Water Soluble Cl (%)	7 ± 4	4 ± 2
Mannitol Ext. B (mg kg^{-1})	0.7 ± 0.1	21.8 ± 1.1

3.1.3 Compost Material

Non-separated MSW compost was provided by İSTAÇ A.Ş. of Istanbul Metropolitan Municipality. The compost material was used as received in the greenhouse pot experiments without any further processing. Some basic characteristics of the compost material are provided in Tables 3.1.2, 3.1.3, 3.1.4.

Table 3.1.2 Average total N, Ca, K, P, S, Mg, Na, Fe and Al concentrations of MSW compost produced at İBB-Kemerburgaz composting plant.

Compost	N	Ca	K	P	S	Mg	Na	Fe	Al	Water Sol. Cl
						(%)				
Average	1.60	5.83	1.20	0.29	0.78	0.44	0.48	1.60	1.26	0.60
Std. Deviation	0.09	1.17	0.15	0.04	0.17	0.05	0.08	0.33	0.31	0.05
% Variation	6	20	12	13	21	11	18	21	24	8
Minimum	1.44	4.37	0.93	0.22	0.61	0.39	0.38	1.16	0.91	0.51
Maximum	1.66	6.95	1.34	0.33	1.02	0.48	0.59	1.94	1.61	0.64

Table 3.1.3 Average total Mn, Cu, Zn, B, Cd, Pb, Ni, Cr, Co and Hg concentrations of MSW compost produced at İBB-Kemerburgaz composting plant.

Compost	Mn	Cu	Zn	B	Cd	Pb	Ni	Cr	Co	Hg
					(mg kg^{-1})					
Average	427	368	633	71	1.42	131	68	136	9.09	0.81
Std. Deviation	81	90	174	28	0.52	30	12	56	2.29	0.15
% Variation	19	24	28	40	36	23	18	41	25	19
Minimum	322	277	405	50	0.90	93	48	80	6.46	0.58
Maximum	506	490	839	126	2.30	174	83	235	12.42	0.91

Table 3.1.4 Average organic matter, total C, C:N, pH, EC, water soluble Cl and agricultural index values of MSW compost produced at İBB-Kemerburgaz composting plant.

Compost	Org.Mad.	C	C/N	pH (1:5)	EC (1:5)	Water Sol. Cl	Agricultural Index
	(%)				(dS/m)	(%)	
Average	46	24	15	7.74	8.2	0.60	4.8
Std. Deviation	4	3	2	0.16	0.4	0.05	0.6
% Variation	9	11	10	2	5	8	12
Minimum	43	21	12	7.54	7.7	0.51	4.4
Maximum	52	27	16	8.02	8.6	0.64	5.6

3.1.4 Chemical Reagents

All chemical reagents used in this study were at least analytical grade from Merck KGaA (Germany) or Sigma Co. (USA). De-ionized water (EC<1 µS cm^{-1}) was used in preparation of chemical solutions and irrigation of experiment plants.

3.2 Methods

3.2.1 Greenhouse Experiment I

All greenhouse experiments were conducted in a Venlo type greenhouse with climatic control. In Greenhouse Experiment-I plastic pots were filled 1800 g of Eskisehir-Sultanönü soil treated with different rates of compost (0%, 1%, 2%, 5% and 10%, w/w) and basal fertilizers (i.e. 100% NPK was composed of 200 mg kg^{-1} N, 100 mg kg^{-1} P, 175 mg kg^{-1} K, 20 mg kg^{-1} S, 2 mg kg^{-1} Fe, and 2 mg kg^{-1} Zn). Initially 20 wheat seeds (*T. ducum* cv. Kümbet), 150 grass seeds (*Festuca rubra* and *Lolium* *perenne)* and 2 lettuce (*Lactuca sativa* cv. Lital 300) seedlings were sown to the pots. Following germination, wheat seedlings were thinned to 10 plants per pot at 11 days after planting (DAP). Pots were watered daily with deionized water as needed. Lettuce and wheat plants were harvested at 35 DAP, whereas grass species were harvested at 70 DAP due to their slower growth rate. The harvested samples were dried at 70^{o}C until a constant weight. Following weighing for dry matter production, all samples were then prepared for chemical analysis.

3.2.2 Greenhouse Experiment II

In Greenhouse Experiment-II plastic pots were filled 1800 g of Eskisehir-Sultanönü or Konya-Çomaklı soil treated with different rates of compost (0%, 2%, 4%, 8%, and 16%, w/w) and basal fertilizer rates (0%, 33%, and 100% of the sufficient rate). For Zn-adequate plants (+Zn) 2 mg kg^{-1} of fertilizer Zn was applied in the form of $ZnSO_4$. Initially 15 seeds (*T. durum* cv. Kümbet) were sown and at 15 DAP seedlings were thinned to 10 per pot. Pots were watered daily with deionized water as needed. Plants were harvested at 43 DAP and shoot samples were dried at 70^{o}C until a constant weight. Following weighing for dry matter production, all samples were then prepared for chemical analysis.

3.2.3 Greenhouse Experiment III

In Greenhouse Experiment-III plastic pots were filled 1700 g of Eskisehir-Sultanönü soil treated with different rates of compost (0%, 4%, and 8%, w/w) and basal fertilizers (i.e. 100% NPK was composed of 200 mg kg^{-1} N, 100 mg kg^{-1} P, 175 mg kg^{-1} K, 20 mg kg^{-1} S, 2.5 mg kg^{-1} Fe and 2 mg kg^{-1} Zn). The compost used in Greenhouse Experiment III was produced with addition of different rates of zeolite and vinasse (1%, 3%, 6% zeolite and 5%, 10%, 15% vinasse) to test the effect of these additives on availability of Na, B and heavy metals in the compost product. Initially six maize seeds (*Zea mays* cv. Shemal) were sown and at 7 DAP seedlings were thinned to 3 per pot. Pots were watered daily with deionized water as needed. Plants were harvested at 21 DAP and shoot samples were dried at 70^{o}C until a constant weight. Following weighing for dry matter production, all samples were then prepared for chemical analysis.

3.2.4 Chemical Analysis of Plant Shoots

All shoot samples were ground to fine powder in a vibrating agate cup mill. About 200 mg of ground sample was wet digested with 65% HNO_3 in a closed vessel microwave system (CEM MarsExpress, USA). The digested samples were filtered and analyzed for mineral nutrients (except N) and heavy metals by ICP-AES (VistaPro Axial, Varian Inc., Australia). Total N was analyzed by a C/N analyzer (TruSpec CN, Leco Co., USA). A NIST (National Institute of Standards and Technology, Gaithersburg, USA) standard reference material was used in every batch of 40 samples to check accuracy and repeatability of the chemical analysis results.

3.2.5 Incubation Experiment

Plastic pots were filled 1700 g of Eskisehir-Sultanönü soil and Konya-Çomaklı soil treated with different rates of compost (0%, 2%, 4%, 8%, and 16%, w/w). All pots were irrigated to 70% of field capacity with distilled water and incubated in greenhouse conditions for six months. Irrigation was repeated every 3-5 days throughout the incubation period to imitate natural conditions of drying-wetting cycles. At sampling (i.e. 1, 30, 90 and 180 days after initiation of incubation) the soil in each pot was thoroughly mixed and ~10 g of sample was placed in plastic bags. All samples were then analyzed for pH (1:5), EC (1:5), Cl (1:5), total C and N, DTPA (Lindsay and Norvell, 1978) and Mehlich-III (Mehlich, 1984) extractable mineral nutrients and heavy metals and mannitol extractable B (Bingham, 1982). All chemical analysis was performed by ICP-AES except for N, C, and Cl. Total N and C was analyzed by a C/N analyzer (TruSpec CN, Leco Co., USA) and Cl was analyzed by a chloridemeter (Jenway PCLM3, UK).

4 RESULTS

4.1 Experiment I: Effect of Municipal Solid Waste Compost Application on Growth, Mineral Nutrition and Heavy Metal Accumulation of Lettuce, Wheat and Grass

4.1.1 Leaf Symptoms and Dry Matter Production

In Experiment I lettuce, wheat and grass species were tested as model plants with increasing rates of compost applications. In lettuce, all compost rates had a positive effect on shoot dry matter yield. The highest yield was obtained at 2% compost application with an increase in dry matter by 19% from 2.75 g plant^{-1} to 3.26 g plant^{-1} (Table 4.1.1; Figure 4.1.1). However at higher rates the increase in dry matter yield was to a lesser extent. At 10% compost application the dry matter yield was only increased by %7. In wheat and *Festuca rubra* 10% compost application resulted in loss of dry matter yield when compared to untreated control plants (Table 4.1.1; Figure 4.1.1). For both species, 2% of compost provided the highest dry matter production. Among the species tested *Lolium perenne* yielded best when compost was applied at 10%. There was no evident reduction in the yield of *Lolium perenne* at any compost application rate, however there was a tendency to increase in yield even at the highest (i.e. %5 and %10) application rates.

In lettuce chlorosis and necrosis of leaf tips occurred when compost was applied at rates over 2%. These symptoms occurred only at the leaf tips of oldest leaves and corresponded to typical toxicity symptoms of salt stress (Figure 4.1.1).

Table 4.1.1 Shoot dry matter production of lettuce (*Lactuca sativa* cv. Lital 300), wheat (*T. durum* cv. Kümbet 2000) grown for 35 days and grass (*Festuca rubra* and *Lolium perenne*) grown for 70 days with different compost application rates.

Compost	Lettuce (cv.Lital 300)		Wheat (cv. Kümbet 2000)		Grass1 (Festuca rubra)		Grass2 (Lolium perenne)	
(%)	(g DM plant^{-1})							
0	2.75 ± 0.28	(100)	0.44 ± 0.03	(100)	0.20 ± 0.01	(100)	0.28 ± 0.01	(100)
1	3.15 ± 0.07	(115)	0.46 ± 0.02	(104)	0.20 ± 0.01	(99)	0.30 ± 0.01	(107)
2	3.26 ± 0.16	(119)	0.48 ± 0.02	(108)	0.21 ± 0.02	(104)	0.29 ± 0.01	(104)
5	3.17 ± 0.18	(116)	0.43 ± 0.03	(98)	0.20 ± 0.02	(103)	0.30 ± 0.01	(108)
10	2.94 ± 0.20	(107)	0.37 ± 0.03	(84)	0.19 ± 0.02	(96)	0.31 ± 0.02	(111)

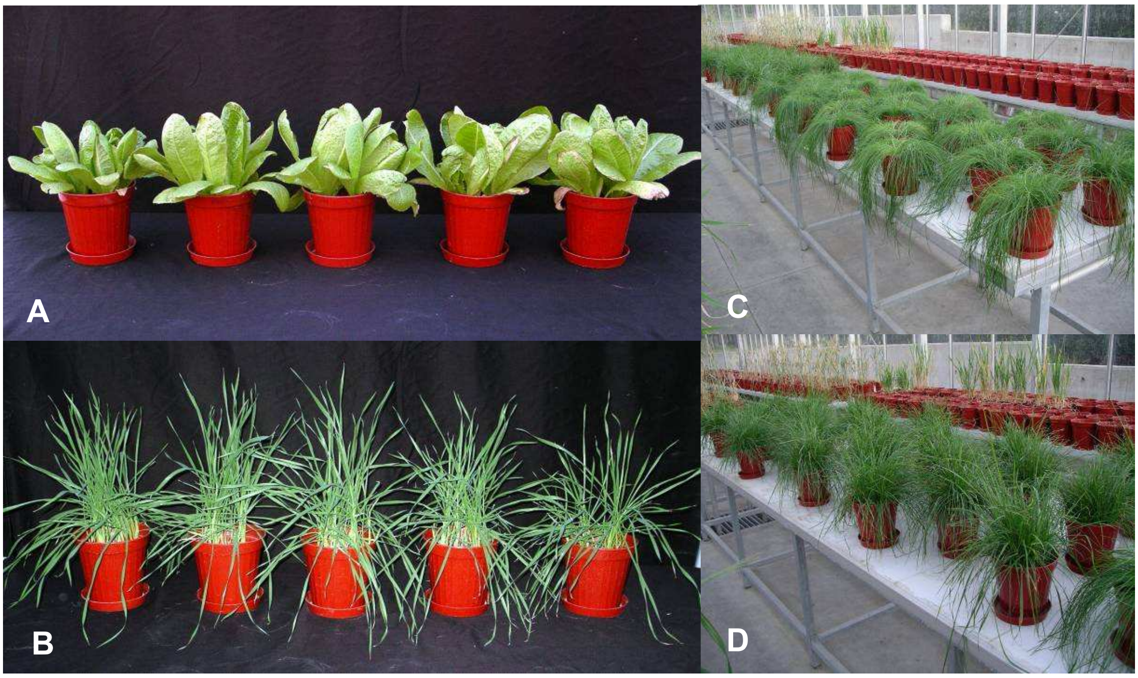


Figure 4.1.1 The effect of different compost application rates (from left to right 0%, 1%, 2%, 5%, 10%) on growth of lettuce (A: *Lactuca sativa* cv. Lital 300) and wheat (B: *T. durum* cv. Kümbet 2000) grown for 35 days under greenhouse conditions and the appearance of grass species (C: *Festuca rubra* and D: *Lolium perenne*) grown for 70 days under greenhouse conditions.

4.1.2 Shoot Mineral Nutrient and Heavy Metal Concentrations

In all species tested, compost treatments resulted in significant changes in macro nutrient concentrations of shoots. While compost applications had positive effects on K and S, nutrition of plants, concentration of Na also increased significantly (Figure 4.1.2). This finding supported that the reason for the occurrence of leaf tip necrosis is because of Na toxicity due to high compost application rates (Figure 4.1.1 and 4.1.2). In line with this finding, wheat plants showed Na accumulation in leaves exceeding the critical levels (>0.35%) when plants were treated with 5% and 10% compost.

While compost applications had positive effects on wheat shoot S, P, and K concentration, Ca and Mg showed decreases with increasing compost applications which may be due to Na toxicity and/or the antagonistic relationship between K and Mg uptake. However, shoot Mg concentrations did not decline to the critical deficiency values (< 0.1% Mg) event at the highest compost rates. Therefore, practically the antagonistic effect of compost on Mg nutrition should not be considered as a critical problem, unless when applied to severely Mg deficient soils (Figure 4.1.1).

Compost treatments had no significant effect on Ca and Mg concentrations of grass species. In grass species shoot Na accumulation due to compost was less pronounced particularly for *Festuca rubra*. Both species had lower shoot Na values compared to wheat and lettuce and Na values in grass species were also found below the critical toxic level (Na> 0.35%) (Figure 4.1.2).

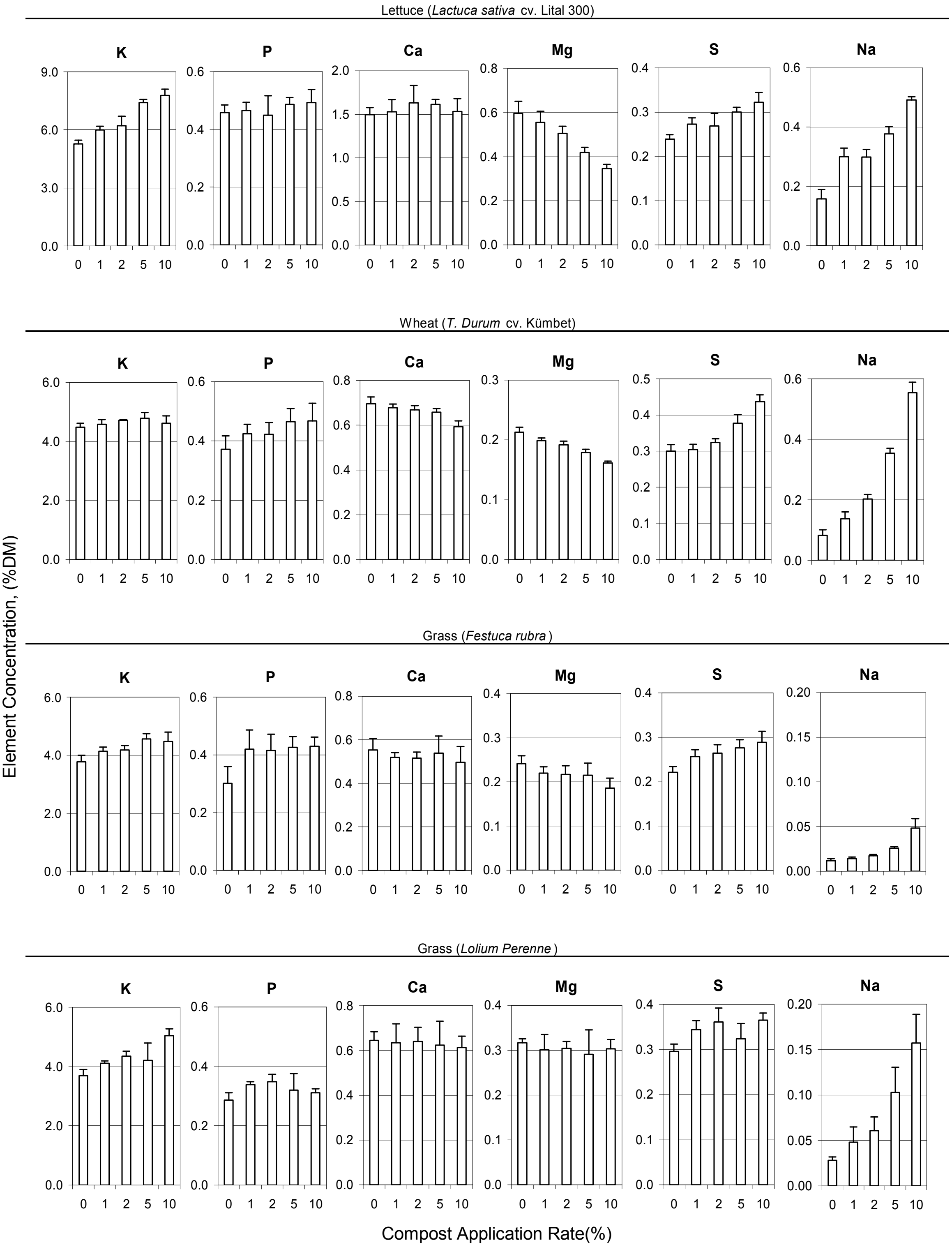


Figure 4.1.2 Effect of increasing compost application rates on macro nutrients and Na concentration in lettuce (*Lactuca sativa* cv. Lital 300), wheat (*T. durum* cv. Kümbet 2000) and grass species (*Festuca rubra* and *Lolium perenne*).

With compost applications, shoot Zn, Cu and Mn concentrations showed significant increases, where as at high compost rates shoot Al and Fe concentrations were observed to decrease in lettuce (Figure 4.1.3). Concerning micro nutrients, the most dramatic change was observed in shoot Zn concentration. Zinc concentration of control plants (i.e. 21 mg kg^{-1}) increased by 2 to 9 fold as a result of 1% and 10% compost applications respectively (Figure 4.1.3). The effect of compost on Zn nutrition appeared also in wheat plants. For example, with 2% compost application, wheat shoot Zn concentration raised more than two fold. Wheat Cu nutrition was also affected positively with compost applications. In contrast to lettuce, it was observed that shoot Mn concentrations of wheat plants showed a significant decrease with compost application (Figure 4.1.3). Nevertheless, shoot Mn concentration never reached critical deficient level (20 mg kg^{-1}) even when 10% compost was applied to the soil. On the other hand, a remarkable increase in shoot B concentration on wheat plants was seen (Figure 4.1.3).

Compost applications had significant effects on shoot micronutrient status of grass species in the order of Zn>Cu>Mn>B. Similar to wheat and lettuce, shoot Zn concentrations were also enhanced dramatically in *Fectuca rubra* and *Lolium perenne* (i.e. 3-4 fold with 10% compost) (Figure 4.1.3). Interestingly compost had only a little effect on shoot B status of *Lolium perenne* compared to *Festuca rubra* or durum wheat. While shoot B concentration of *Festuca rubra* increased by 3 fold, no significant effect on B was evident in *Lolium perenne* upon increasing rates of compost treatments (Figure 4.1.3).

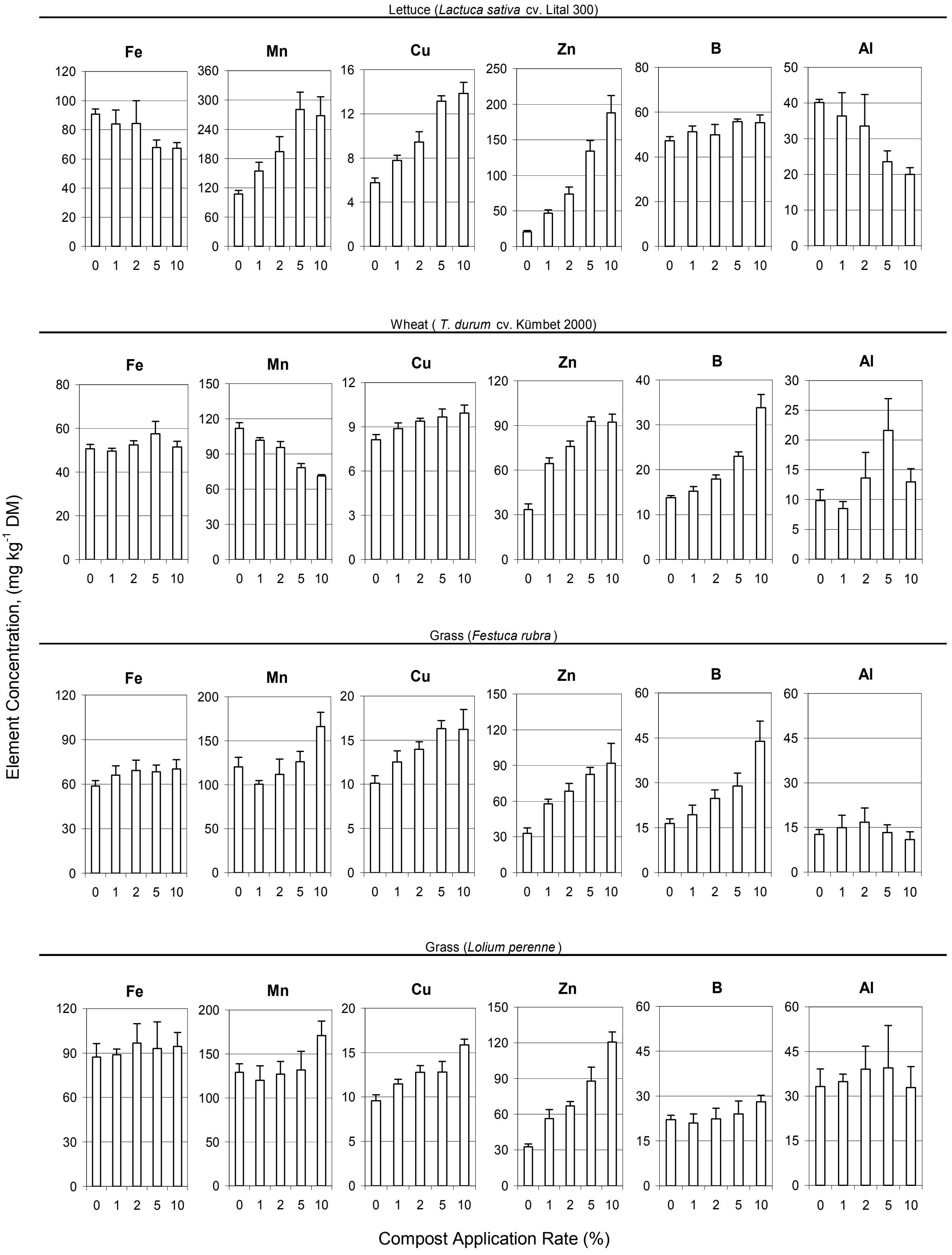


Figure 4.1.3 Effect of increasing compost application rates on micro nutrients and Al concentration in lettuce (*Lactuca sativa* cv. Lital 300), wheat (*T. durum* cv. Kümbet 2000) and grass species (*Festuca rubra* and *Lolium perenne*).

The results of heavy metal analysis showed that only concentration of Cd was enhanced with compost applications, particularly in lettuce (Figure 4.1.4). When control plants (i.e. no compost treatment) are compared it can be seen that Cd concentration of lettuce is far above the other species, suggesting that lettuce is a good accumulator of Cd. Among the heavy metals studied, there was no significant effect on Cr and Pb, while Co and Ni values tended to decrease in respect to high compost rates.

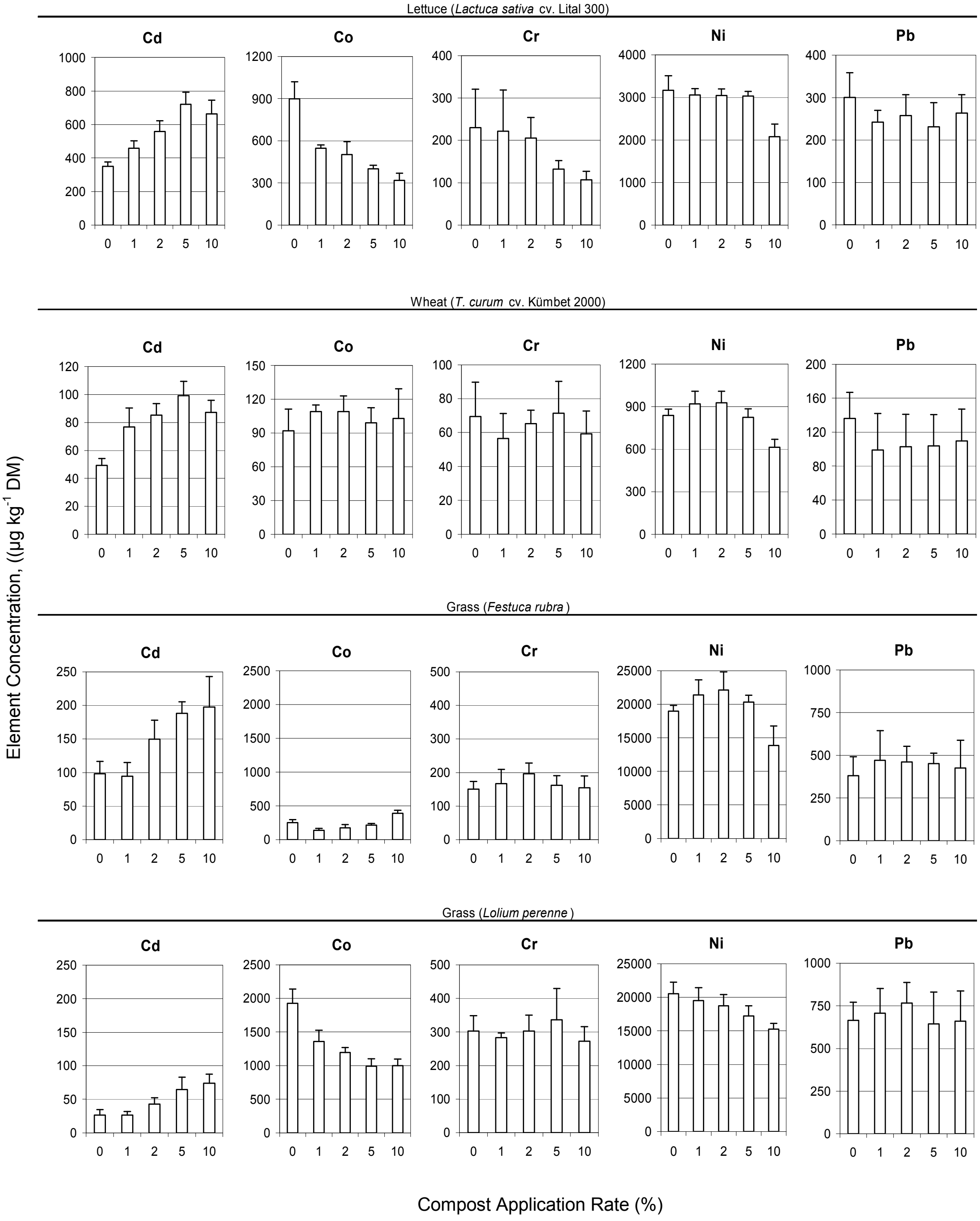


Figure 4.1.4 Effect of increasing compost application rates on heavy metal concentration in lettuce (*Lactuca sativa* cv. Lital 300), wheat (*T. durum* cv. Kümbet 2000) and grass species (*Festuca rubra* and *Lolium perenne*).

4.2 Experiment II: Effect of Compost and Basal Fertilizer Treatments on Shoot Dry Matter Yield, Mineral Nutrition and Heavy Metal Accumulation in Wheat Grown in Problematic Soils with Zinc Deficiency and Boron Toxicity

4.2.1 Experiment IIa: Greenhouse Experiments with Zn-Deficient Soil

4.2.1.1 Leaf Symptoms and Shoot Dry Matter Production

By using a severely Zn-deficient soil (Eskisehir-Sultanönü soil) from Central Anatolia region of Turkey, a greenhouse pot experiment has been conducted to study the effect of increasing rates of compost (0%, 2%, 4%, 8% and 16% [w/w]) and basal NPK fertilizer applications (0%, 33% and 100% of the sufficient basal dose) on growth, mineral nutrition and heavy metal accumulation of a durum wheat cultivar (*T. durum* cv. Kümbet) selected as a model plant species.

Increasing rate of compost applications resulted in substantial enhancement of shoot biomass production, particularly at low fertility conditions (i.e. 0% and 33% basal fertilizer without Zn treatment) (Figure 4.2.1 and 4.2.2). The effect of compost on dry matter yield was less pronounced under sufficient Zn and basal NPK fertilizer treatments. (Figure 4.2.1 and Figure 4.2.2). The most significant effect of compost amendments had occurred when no basal fertilizer and Zn was applied to the soil (Figure 4.2.1 and 4.2.2). Under this condition (i.e. without Zn or NPK) shoot dry matter was doubled with 2% compost application and gradually increased up to control conditions (i.e. 100% of basal NPK and Zn supply) with 16% compost application. Under Zn deficient conditions and 100% basal fertilizer supply, 2% compost treatment was enough to compensate the yield loss caused by Zn deficiency and a further increase in compost rate had no additive effect on dry matter production (Figure 4.2.1; Figure 4.2.2).

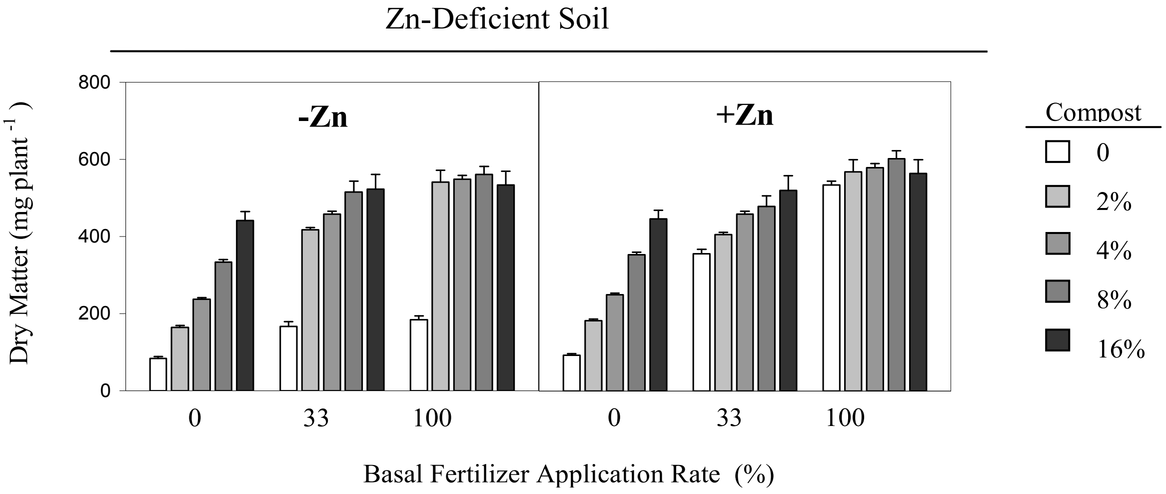


Figure 4.2.1 Effect of increasing municipal solid waste compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot dry matter yield of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with Zn deficient Sultanönü Eskişehir soil (100% basal fertilizer was composed of 200 mg kg^{-1} N, 100 mg kg^{-1} P, 175 mg kg^{-1} K, 20 mg kg^{-1} S and 2.5 mg kg^{-1} Fe, in the case of +Zn, 2 mg kg^{-1} Zn was applied).

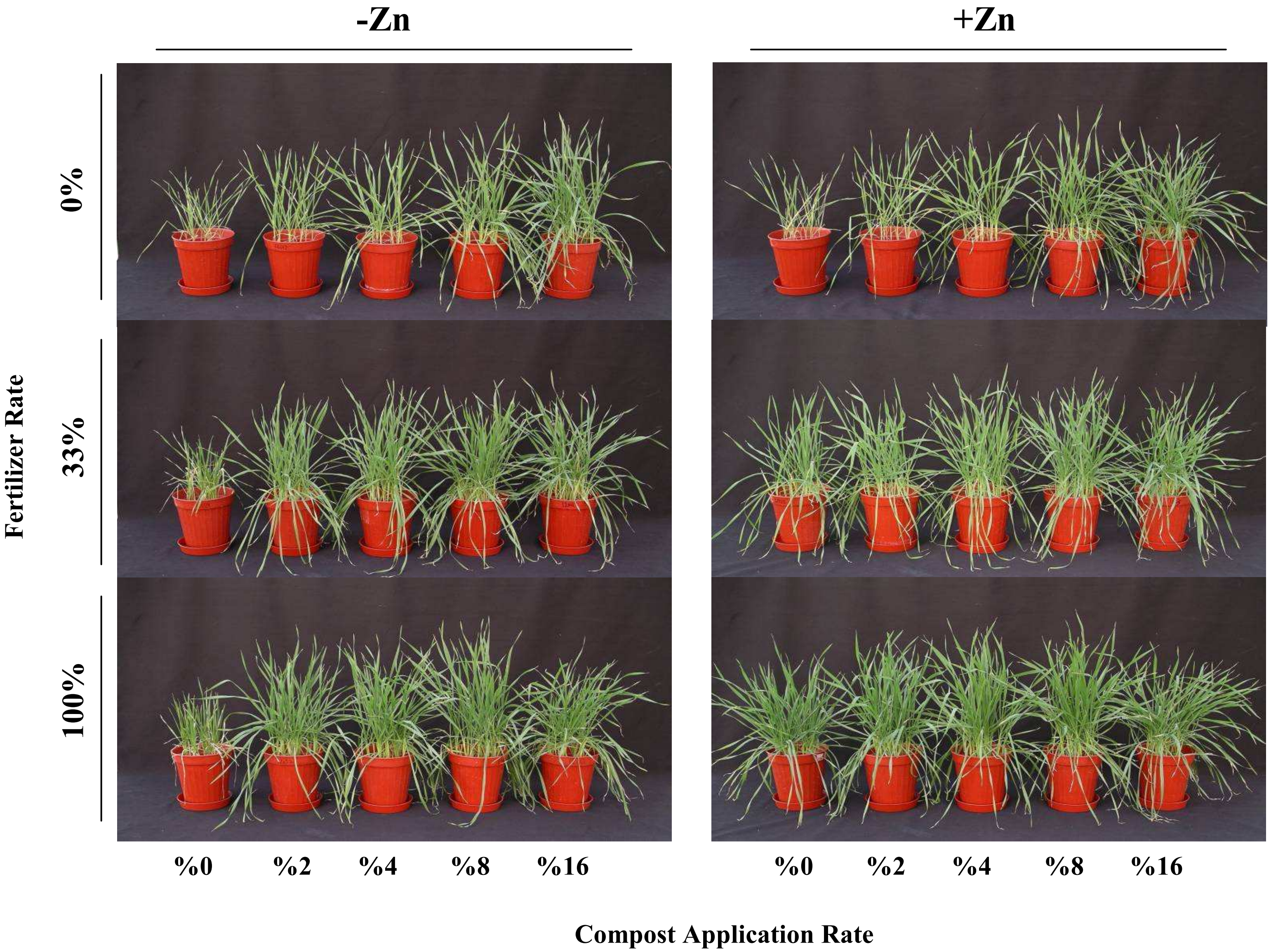


Figure 4.2.2 Wheat plants (*T. durum* cv. Kümbet) grown with different compost, fertilizer and Zn applications in Zn deficient Eskişehir-Sultanönü soil.

4.2.1.2 Shoot Mineral Nutrient and Heavy Metal Concentrations

As expected, concentration of macro nutrients showed increases from low to sufficient level of fertilization (Figure 4.2.3). In the case of sufficient fertilization without Zn fertilizer, concentrations of macro nutrients in shoot were found to be higher. This is mainly originated because of the “concentration effect” related to the decline in biomass caused by Zn deficiency.

Compost applications resulted in significant changes in macro nutrients in shoots both under sufficient or deficient Zn conditions. In general compost had positive effects on nutrition with N, S, K, and P (Figure 4.2.3). The positive effects of compost on macronutrient nutrition was more evident under low fertilizer rates (i.e. 0% and 33% basal NPK). Shoot Ca was increased to some extent with lower compost doses. There was gradual decrease in Mg in respect to increasing compost rates. Shoot Na concentration was dramatically enhanced exceeding the critical level (>0.35%) at 8% compost rate (Figure 4.2.3).

The most significant effect of increasing levels of compost applications has been on shoot Zn concentration among micronutrients. When plants were grown on Zn deficient Sultanönü soil without any Zn addition, shoot Zn concentration was found to be below the critic deficiency level (<15 mg kg^{-1}). With 2 mg kg^{-1} $ZnSO_4$ application on soil, shoot Zn concentration was increased by 5-6 folds arising to 24, 33 and 30 mg kg^{-1} in the case of 0%, 33% and 100% basal fertilizer rates respectively (Figure 4.2.4). On the other hand, the minimal amount of compost application (2%) enhanced shoot Zn concentration 3 times more than chemical Zn application ($ZnSO_4$) did. Besides the effects of compost on shoot Zn concentration, compost applications had positive effects on shoot B, Cu, and Mo concentrations. These impacts have become more pronounced when basal fertilizer rate is low (Figure 4.2.4).

Shoot Zn concentration was around 5 mg kg^{-1} which is below the critical level (i.e. <15 mg kg^{-1}) in treatments without compost and Zn application. When soil was supplied with 2 mg kg^{-1} of Zn in $ZnSO_4$ form, shoot Zn concentration was increased by 5-6 folds, meeting the sufficient levels. The most significant effect of compost on micronutrients was for Zn. All compost applications substantially enhanced shoot Zn concentrations in a dose dependent manner. The lowest application rate of 2% was enough to increase Zn status of plants far above the critical levels (Figure 4.2.4).

Compost was highly effective in increasing the concentration of Fe, Cu, Mo and B, particularly at low basal fertilizer treatments. However, shoot Mn was not affected by compost or basal fertilizer treatments.

Concerning heavy metal accumulation by compost treatments, only Cd tended to increase in shoot samples (Figure 4.2.5). Heavy metals such as Pb, Hg, Ni, Cr, Co, and Al did not show any significant change with compost applications (Figure 4.2.5). The increase in Cd concentration was not found significant because Cd values were far below critical level of 0.2 mg kg^{-1} (Figure 4.2.5). Interestingly, when plants received no Zn fertilizer and compost treatment, Cd concentration was about two fold due to the "concentration effect" (Figure 4.2.5).

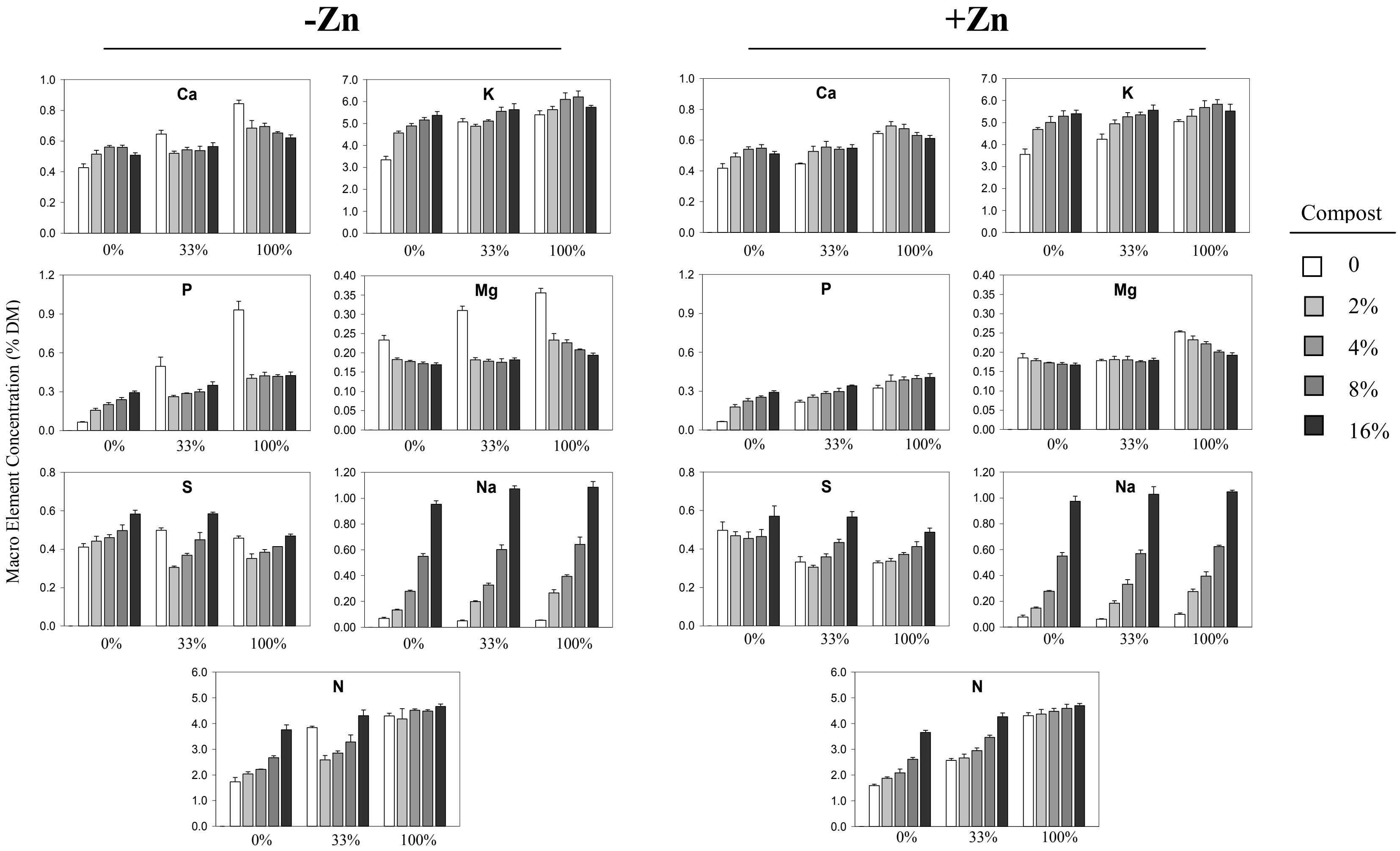


Figure 4.2.3 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot macro element concentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with Zn deficient Eskişiehir-Sultanönü soil.

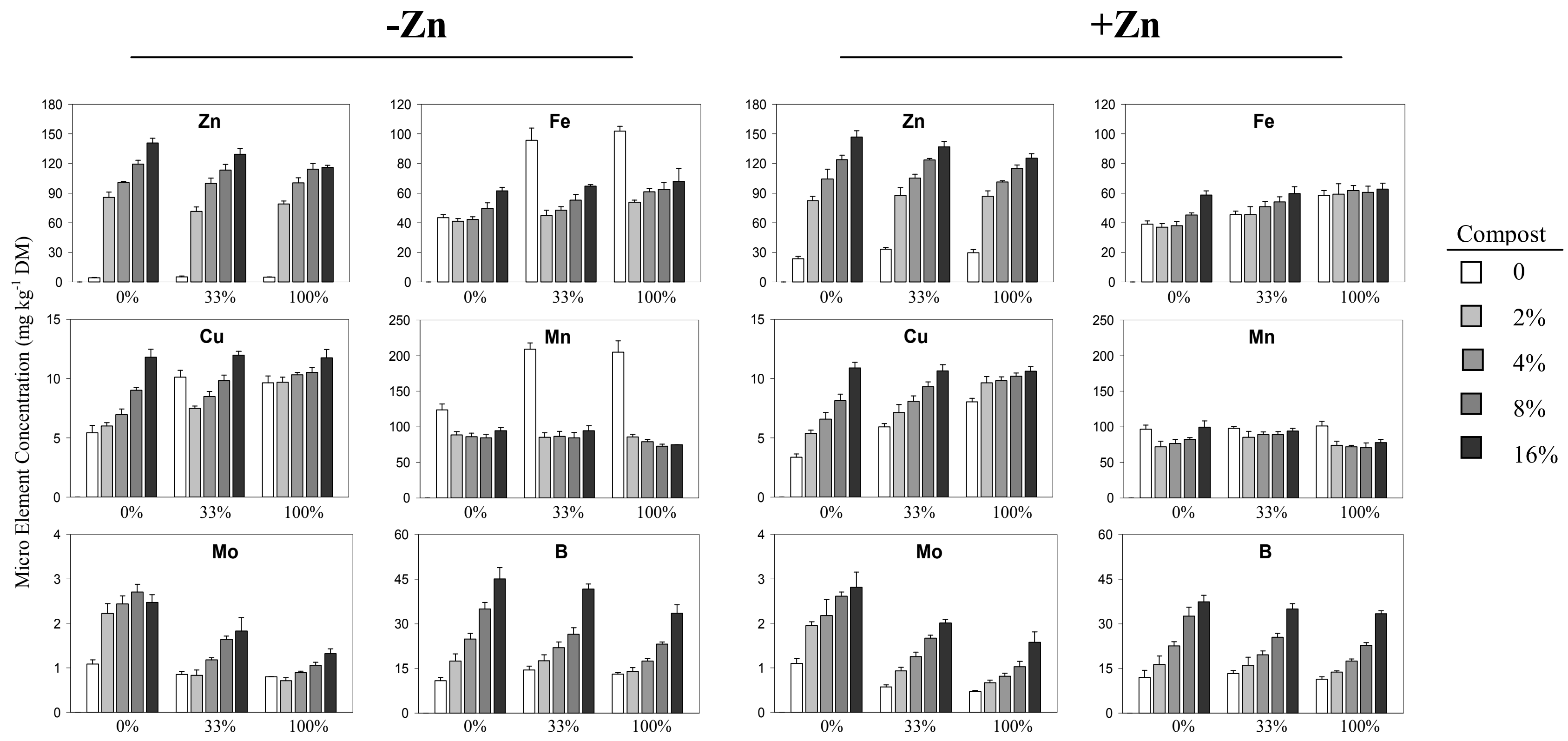


Figure 4.2.4 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot micro element concentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with Zn deficient Eskişiehir-Sultanönü soil.

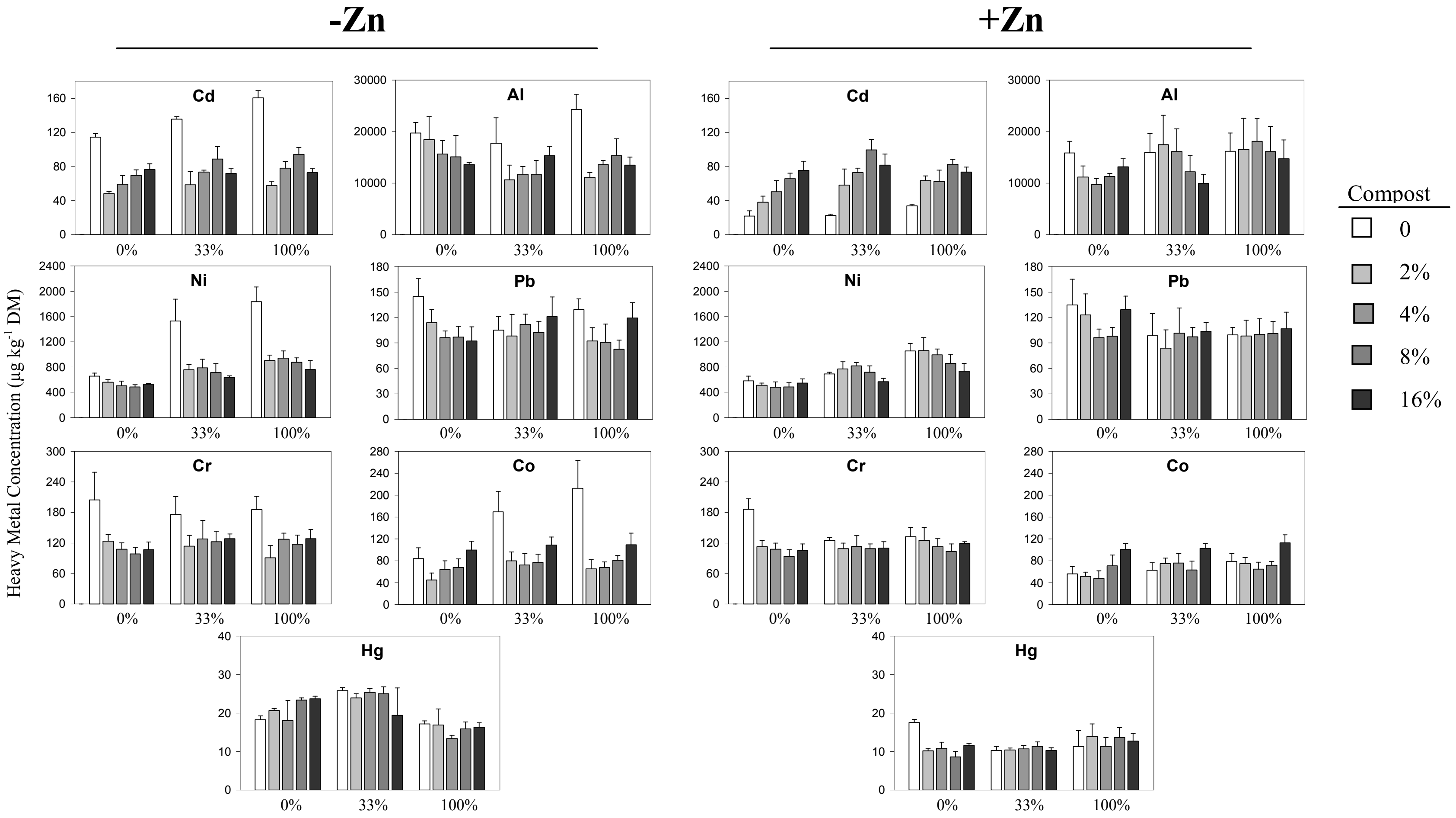


Figure 4.2.5 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot heavy metalconcentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with Zn deficient Eskişiehir-Sultanönü soil.

4.2.2 Experiment IIb: Greenhouse Experiments with B-Toxic Soil

4.2.2.1 Leaf Symptoms and Shoot Dry Matter Production

The aim of this greenhouse experiment was to test the effects of increasing rates of compost (0%, 2%, 4%, 8% and 16% [w/w]) and basal NPK fertilizer applications (0%, 33% and 100% of the sufficient basal dose) on growth, mineral nutrition and heavy metal accumulation of a durum wheat cultivar (*T. durum* cv. Kümbet) grown in Konya-Çomaklı soil. This specific soil is known to have severe B toxicity and Zn deficiency problems together.

Plants responded to basal fertilizer treatments with increase in shoot dry matter yield under sufficient Zn conditions (Figure 4.2.6 and 4.2.7). In the case of no Zn treatment, addition of basal fertilizers had no or even a negative effect on yield. The most distinctive increase in dry matter production was observed when the soil was amended with compost under Zn deficient conditions with sufficient NPK treatment (Figure 4.2.6 and 4.2.7). Under Zn deficient conditions and 100% basal fertilizer supply, 2% compost treatment totally recovered Zn deficiency. Increase in compost rate above 2% had no additive effect on dry matter production (Figure 4.2.1; Figure 4.2.2). Compost addition had very little or no effect when the soil was supplied with Zn and basal NPK fertilizer treatments (Figure 4.2.6 and 4.2.7).

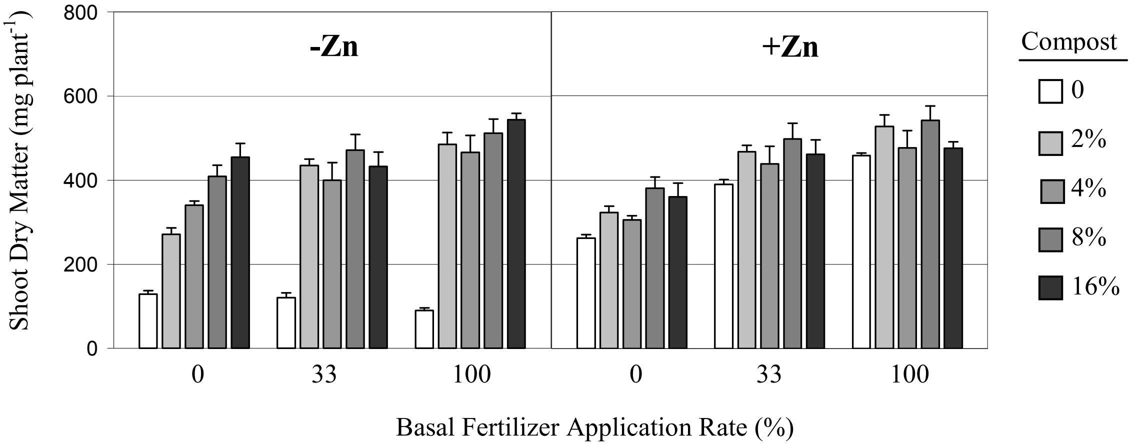


Figure 4.2.6 Effect of increasing municipal solid waste compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot dry matter yield of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with B toxic Konya-Çomaklı soil (100% basal fertilizer was composed of 200 mg kg^{-1} N, 100 mg kg^{-1} P, 175 mg kg^{-1} K, 20 mg kg^{-1} S and 2.5 mg kg^{-1} Fe, in the case of +Zn, 2 mg kg^{-1} Zn was applied).

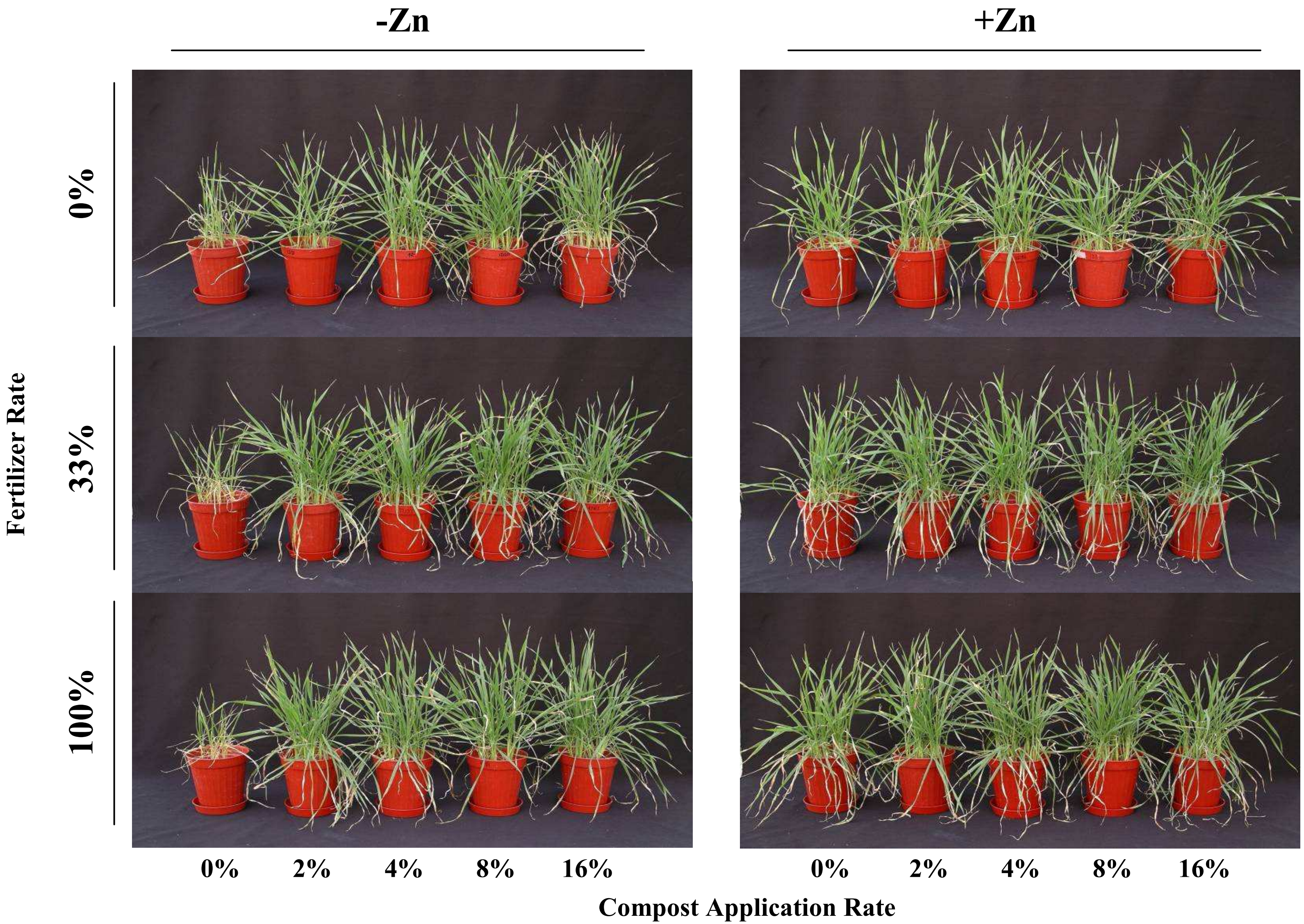


Figure 4.2.7 Wheat plants (*T. durum* cv. Kümbet) grown with different compost, fertilizer and Zn applications in B toxic Konya-Çomaklı soil.

4.2.2.2 Shoot Mineral Nutrient and Heavy Metal Concentrations

Under sufficient Zn conditions, basal NPK treatments contributed to N and P nutrition of plants, whereas shoot K concentration was not affected and S concentration was reduced by basal fertilizer treatments (Figure 4.2.8). In agreement with previous experimental results, P, Mg and Ca were concentrated in the plant shoots due to severe growth retardation by Zn deficiency (Figure 4.2.8). Compost applications were effective particularly in N, S and P nutrition of plants (Figure 4.2.8). It was also confirmed that at very high compost rates (i.e. >8%) shoot Na concentration increased over critical limits (i.e. >0.35%).

In plants grown with the Konya-Çomaklı soil, shoot Zn concentration was around 6-10 mg kg^{-1} (i.e. below the critical limit of 15 mg kg^{-1}) when no Zn and compost was treated (Figure 4.2.9). With Zn supply to soil, Zn concentration was successively increased to 25-34 mg kg^{-1}. Compost applications enhanced micronutrients in the order of Zn>Cu>Mo irrespective of Zn fertilizer treatment to soil (Figure 4.2.9). The pronounced effect of compost applications on micronutrient status of plants was more pronounced for high basal fertilizer conditions (Figure 4.2.9). In contrast with the experiment conducted with Eskisehir-Sultanönü soil, shoot B concentration was significantly reduced with increasing rates of compost applications to Konya-Çomaklı soil. With increasing rate of compost application, shoot B concentration decreased significantly up to 50% (e.g., from 950 to nearly 400 mg B kg^{-1} dry wt). This result clearly showed that addition of compost reduced plant B uptake form a typical B-toxic soil.

Increasing compost rates resulted in concomitant increases in shoot heavy metal concentrations in the order of Cd>Pb>Hg (Figure 4.2.10). Treatment with sufficient basal fertilizers reversed this effect at least for Pb and Hg. The increase in shoot Cd is not considered as a critical limitation, because Cd values of shoot samples were similar in plants with sufficient basal NPK fertilizer but without Zn and compost treatment (Figure 4.2.10). Also the increase in Cd concentration with compost treatments was below the critical limit (i.e. <200 μg kg^{-1}).

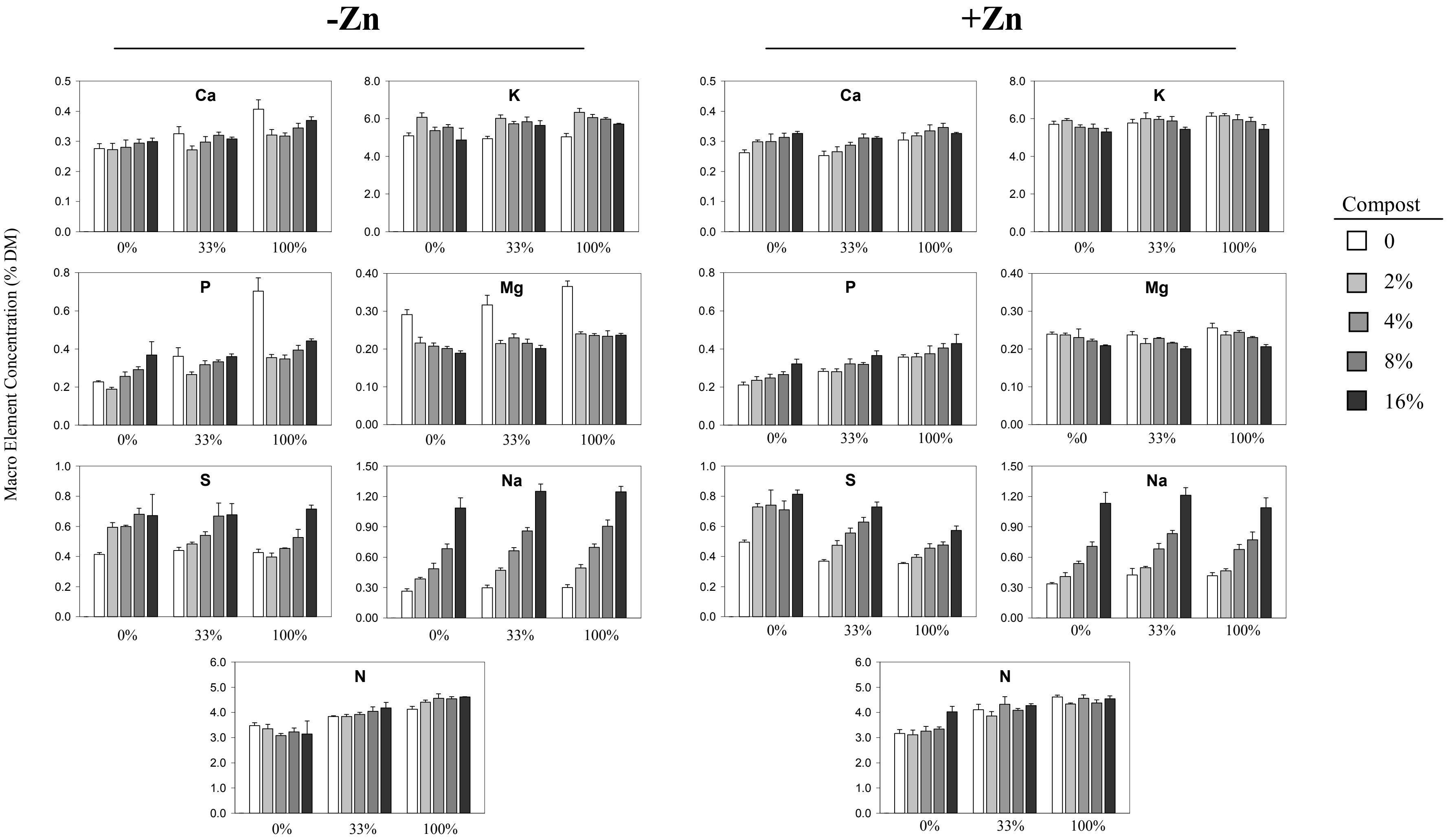


Figure 4.2.8 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot macro element concentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with B toxic Konya- Çomaklı soil.

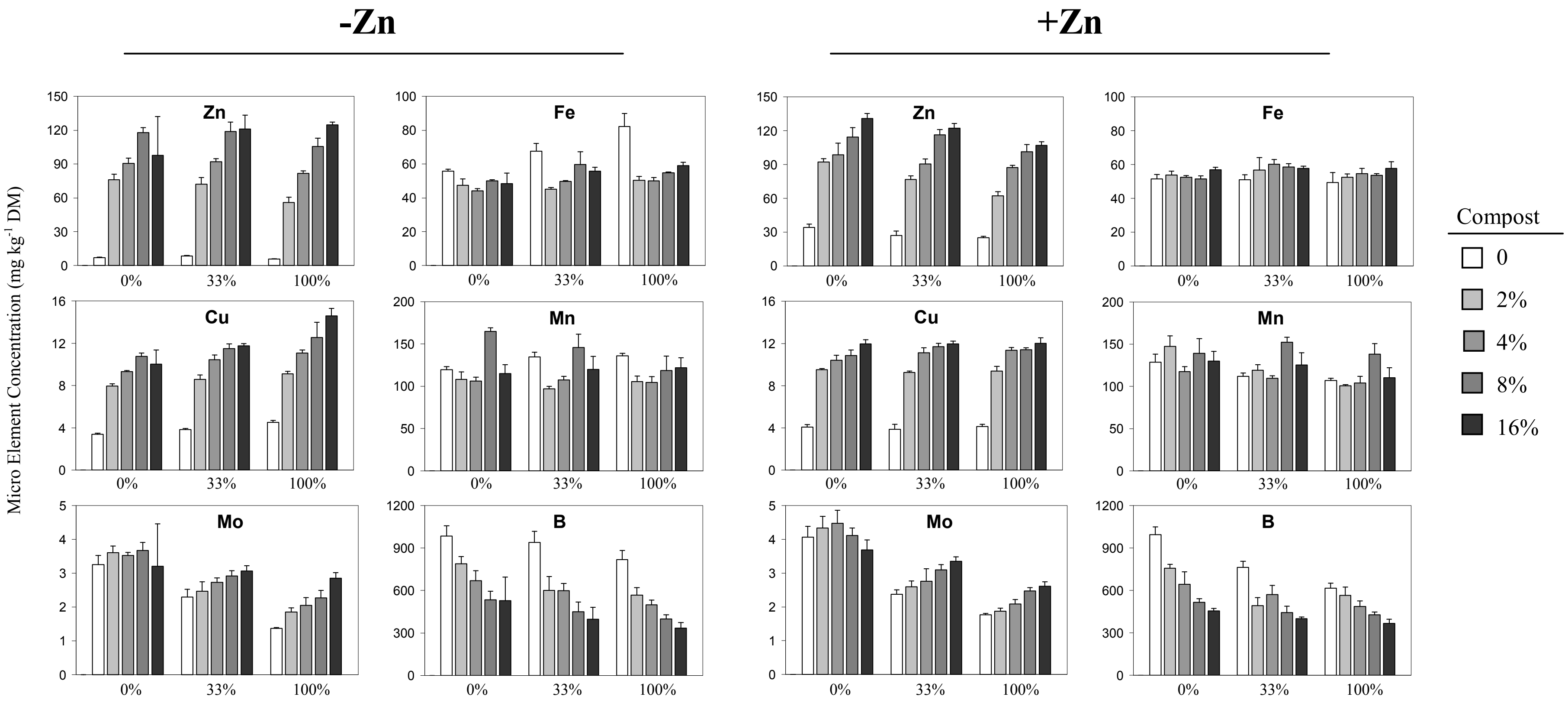


Figure 4.2.9 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot micro element concentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with B toxic Konya- Çomaklı soil..

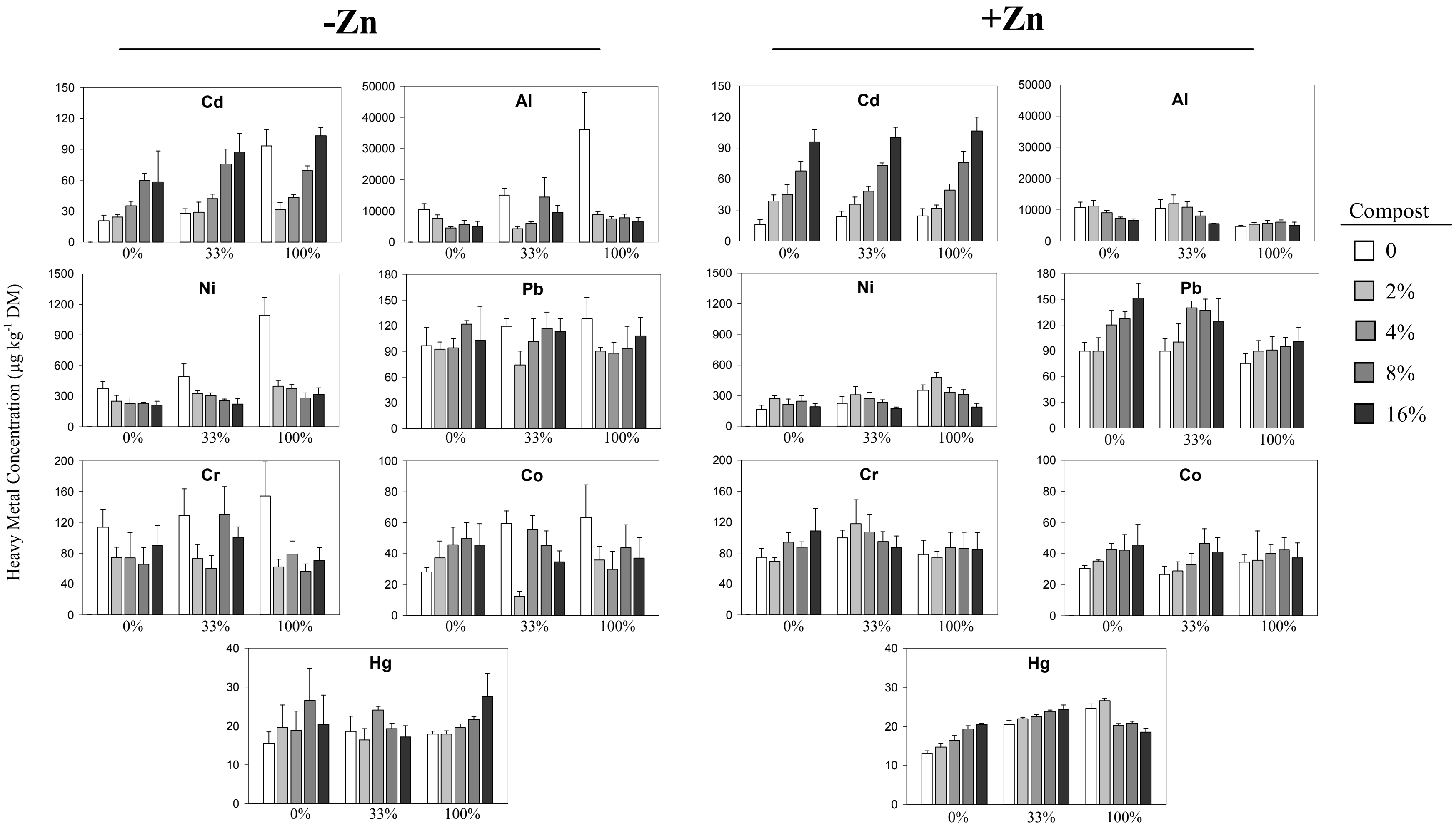


Figure 4.2.10 Effect of compost (0%, 2%, 4%, 8% and 16% [w/w]), basal NPK (0%, 33% and 100% of the sufficient basal dose) and Zn applications on shoot heavy metal concentration of 43 days-old wheat (*T. durum* cv. Kümbet) grown under greenhouse conditions with B toxic Konya- Çomaklı soil..

4.3 Experiment III: Experiments Conducted with Zeolite and Vinasse Amended Compost

4.3.1 Shoot Dry Matter and Production

According to the previous experiments, it was determined that high compost application rates caused heavy metal accumulation in plant shoots. In order to decrease this effect, compost was amended with different rates of zeolite (0%, 1%, 3% and 6%; w/w) or vinasse (0%, 5%, 10%, 15%; w/w) during the composting process. The zeolite, vinasse and control (no additive) composts were then tested in a greenhouse pot experiment conducted with increasing rates (0%, 4%, 8%; w/w) of each compost product and maize (*Zea mays* cv. Shemal) as a model plant.

Irrespective of zeolite and vinasse applications (i.e. –Z/-V), 4% compost treatment had no significant effect on shoot dry matter yield of control plants while 8% compost application reduced shoot dry matter yield by ~10% (Figure 4.3.1). In the case of zeolite amended compost, there was no reduction in yield with 8% compost treatment. However, increase in zeolite amendment did not provide a significant increase in yield. Results show that zeolite addition to compost can prevent yield reductions when compost is applied at high rates (Figure 4.3.1).

In the case of vinasse amended compost, 5% and 10% vinasse amendments hed no significant effect on shoot biomass production when these composts were treated at a rate of 4%, however dry matter yield was negatively affected when 15% vinasse was amended to the compost. At a higher compost rate (i.e. 8%) 10% and 15% vinasse amendments caused significant yield loss, suggesting that vinasse amendment to compost during processing has no beneficial effect on biomass production in maize (Figure 4.3.1).

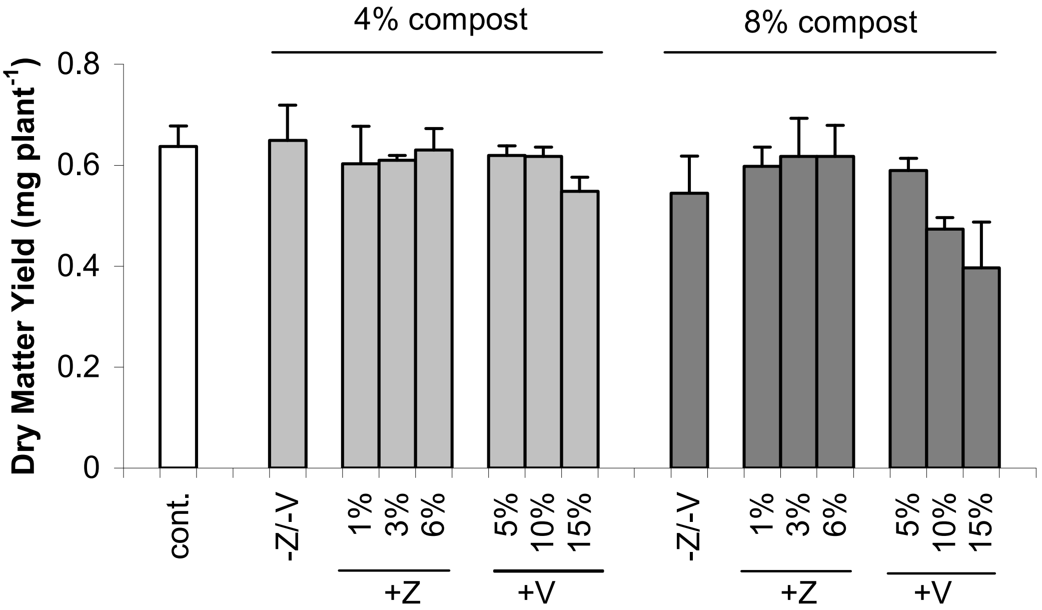


Figure 4.3.1 Effect of zeolite and vinasse amended composts on shoot dry matter yield of 21-day old maize (*Zea mays* cv. Shemal) plants.

4.3.2 Shoot Mineral Nutrient and Heavy Metal Concentrations

When the effect of zeolite and vinasse amended compost treatments was evaluated for macro elements, it was found that the main effect was on Na, followed by changes in Ca, Mg and S values. In well agreement with previous results, shoot Na was enhanced upon compost treatments, however this effect was found to be reversible by zeolite amendment to compost during processing (Figure 4.3.2). Zeolite amendments effectively reduced Na uptake of plants even at 8% compost treatment in a dose depended manner. By using 6% zeolite amended compost, shoot Na values were reduced to the level of control plants (Figure 4.3.2). On the contrary, vinasse amended composts gradually enhanced Na accumulation in shoots. In the case of 8% compost with 15% vinasse amendment, shoot Na was increased by four fold compared to control plans (Figure 4.3.2).

With vinasse application Mg and Ca concentrations tended to decrease and S concentration was slightly increased at 8% compost treatments. Zeolite and vinasse additions to compost had no significant effect on shoot P or K concentration (Figure 4.3.2).

Based on the results, shoot Na concentrations were significantly enhanced with 4 and 8% compost treatments without zeolite and vinasse amendments. In the case of zeolite amended compost treatments, shoot Na concentrations were significantly reduced with increasing zeolite, particularly at the 8% compost treatment (Figure 4.3.2).

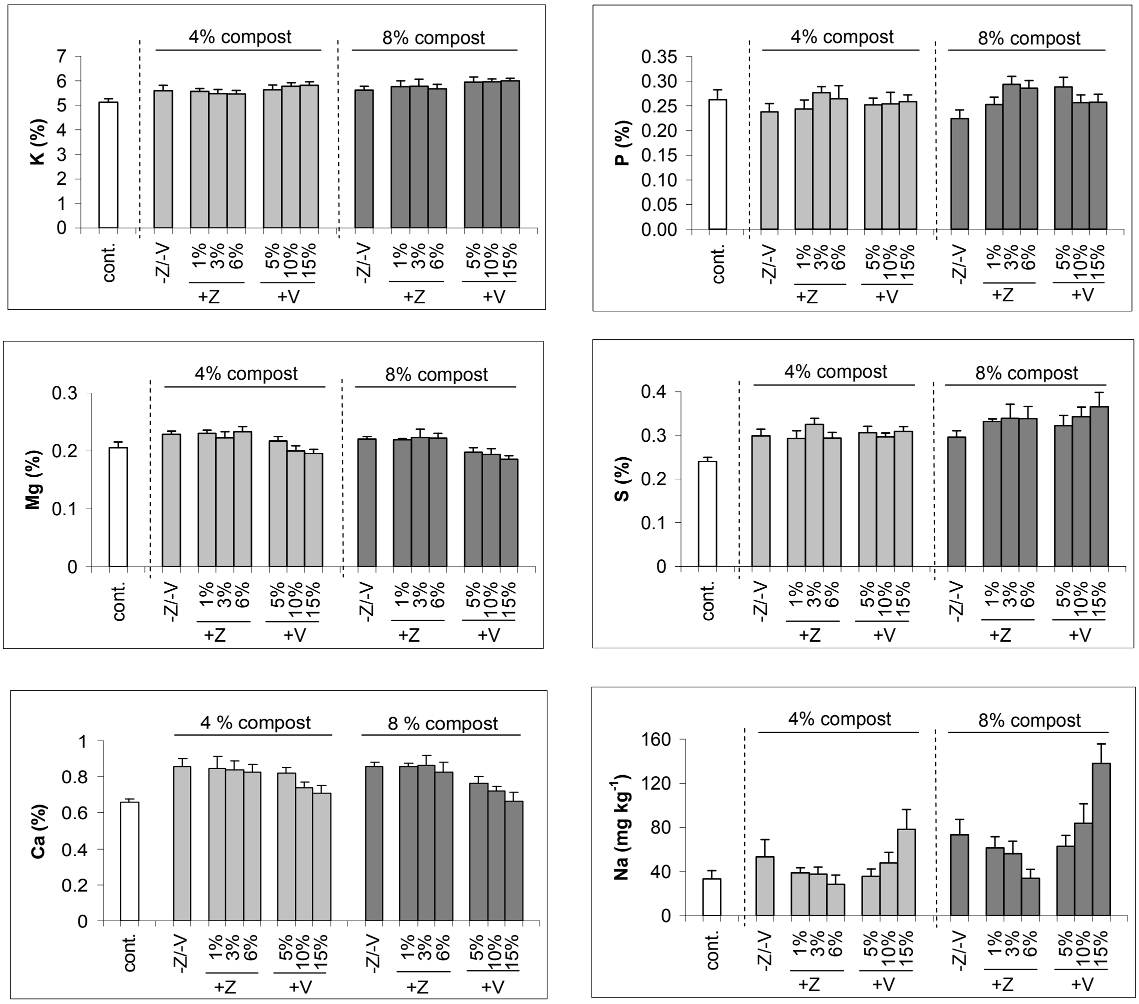


Figure 4.3.2 Effect of zeolite and vinasse amended composts on shoot macronutrient and Na concentration of 21-day old maize (*Zea mays* cv. Shemal) plants.

Results on micronutrients confirmed that increasing rates of compost applications affected mainly Zn and B uptake of plants (Figure 4.3.3). Irrespective of zeolite or vinasse additions, shoot Zn and B concentrations was enhanced by nearly 2.5 fold with compost applications (Figure 4.3.3). Addition of zeolite or vinasse during composting process had no effect on micronutrient nutrition of maize plants with the exception of B (Figure 4.3.3). With addition of zeolite or vinasse to compost there was a remarkable decrease in B concentration of plants compared to compost treatments without additives (i.e. without zeolite or vinasse amendment) (Figure 4.3.3).

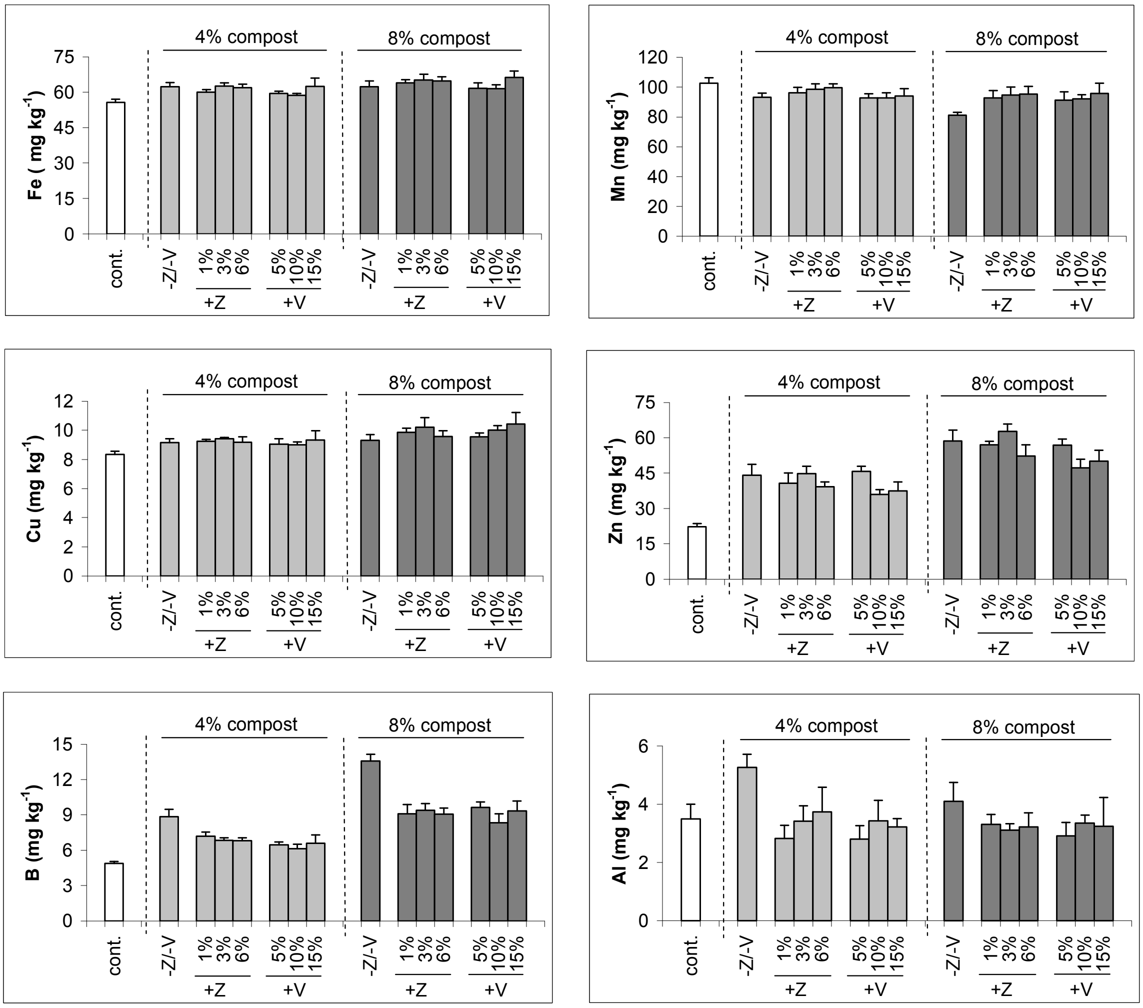


Figure 4.3.3 Effect of zeolite and vinasse amended composts on shoot micronutrient and Al concentration of 21-day old maize (*Zea mays* cv. Shemal) plants.

Confirming the results of previous experiments conducted with different plant species, the main effect of compost treatments on heavy metals was the increase in shoot Cd levels in maize shoots. Shoot Cd concentrations were 84, 156 and 195 μg kg^{-1} for 0, 4 and 8% compost applications respectively. Addition of zeolite had no apparent effect on Cd accumulation, however vinasse addition resulted in enhanced Cd accumulation in maize shoots (Figure 4.3.4). Zeolite or vinasse applications did not have significant effect on shoot Co, Mo, and Ni concentrations. The changes in Cr and Pb concentrations were also not found significant due to high standard deviations (Figure 4.3.4).

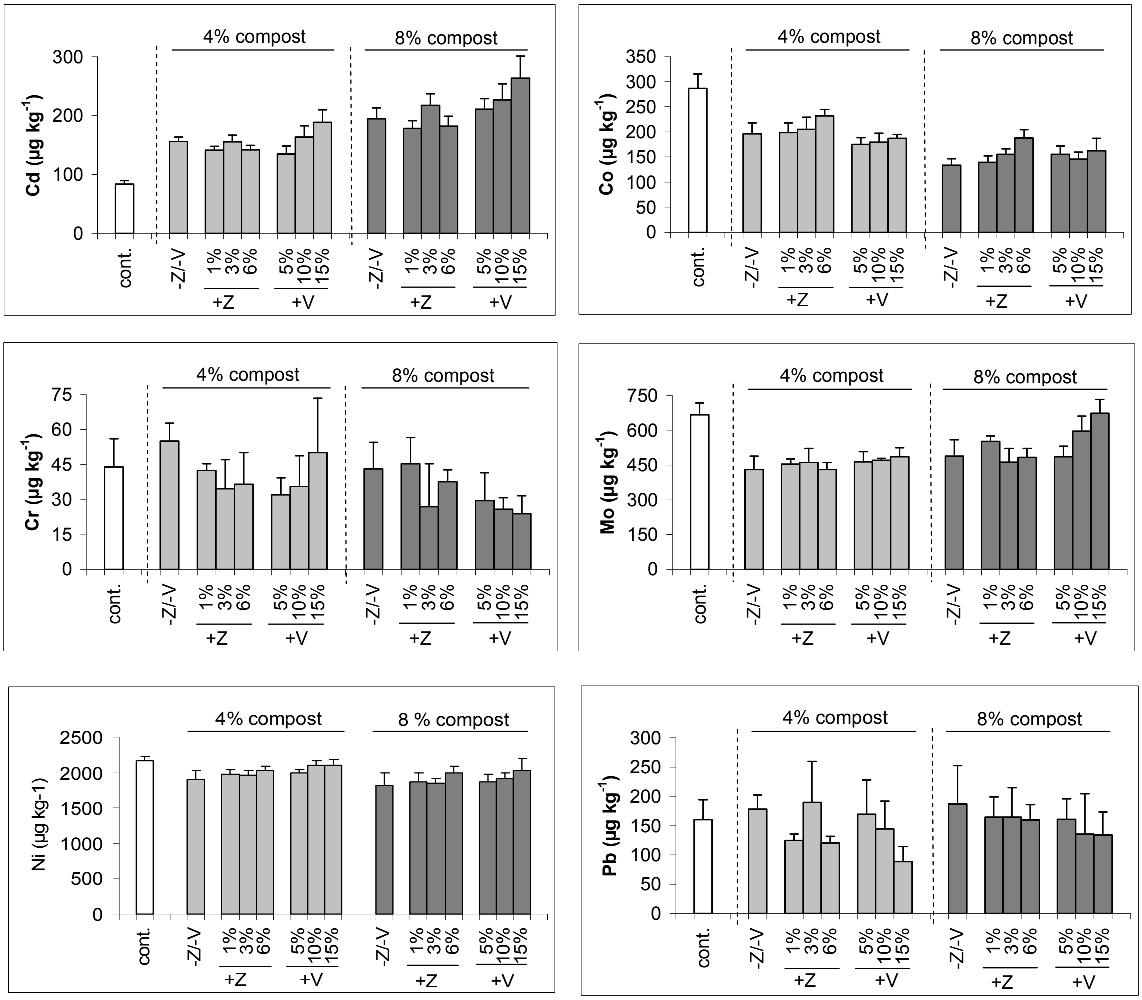


Figure 4.3.4 Effect of zeolite and vinasse amended composts on shoot heavy metal concentration of 21-day old maize (*Zea mays* cv. Shemal) plants.

4.4 Experiment IV: Compost Soil Incubation Experiments

4.4.1 Effect of Incubation on Total C, Total N, pH, EC, and Water Soluble Cl

Çomaklı soil had a substantially higher C level than Sultanönü soil under natural conditions (i.e. control pots with no compost addition). Consequently amendment of soil with compost up to 16% had no significant effect in C content of Çomaklı soil. In Sultanönü soil, compost application gradually increased soil C status from 1.8% to 4.1% (Figure 4.1.1). C The effect of increasing rates of compost applications on soil C, N, and C:N values were given at Figure 4.4.1, Figure 4.4.2, and Figure 4.4.3 respectively. Compost treatments did not have necessary effects on C ratios of Çomaklı soil which includes 7% total C. In the case of Sultanönü soil which has low C status (2%), total C increased by approximately 2 fold with compost application to soil (Figure 4.1.1).

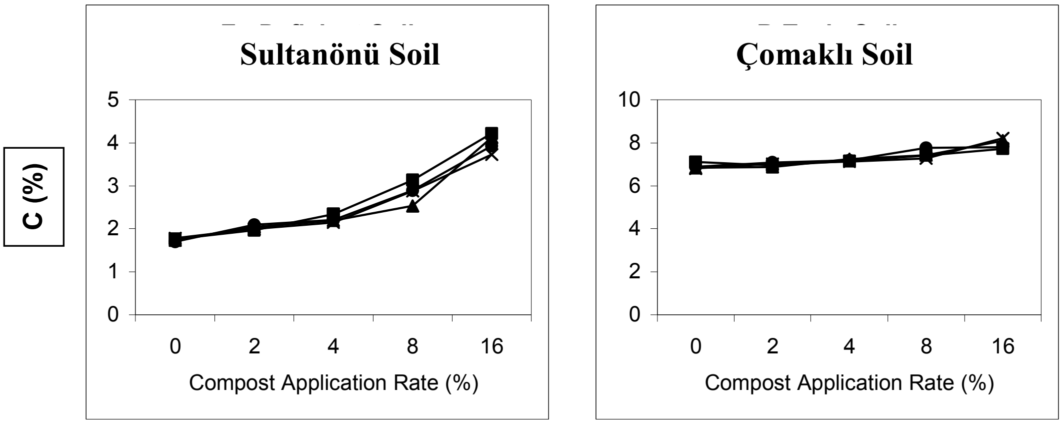


Figure 4.4.1 Effect of compost application on soil C status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation).

Total N concentration of both soils was gradually increased with increasing compost treatments. The effect of compost on N content has been pronounced particularly at 8% and 16% compost rates. For example, N concentration in Sultanönü soil was about 0.15-0.17% in control conditions and 8% compost application enhanced soil N to 0.23-0.29%. Addition of compost also resulted in a similar increase in Çomaklı soil, but N values tended to decrease with incubation time in Çomaklı (Figure 4.4.2).

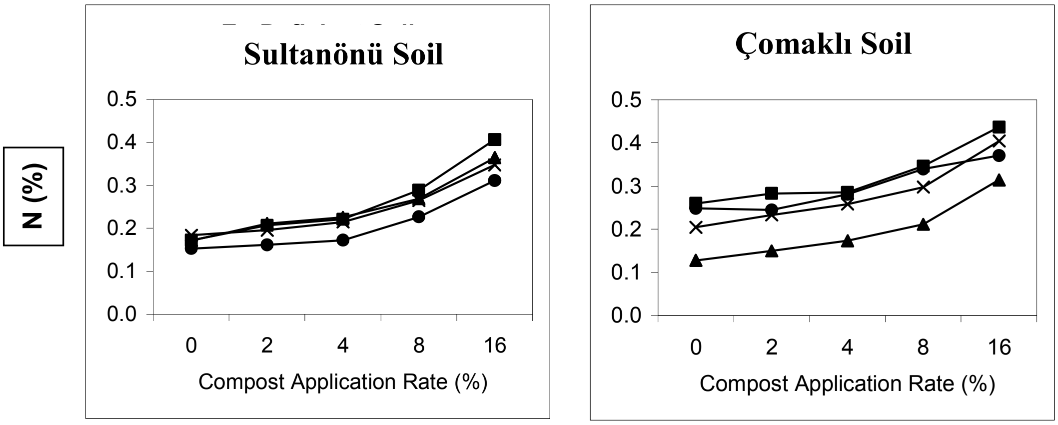


Figure 4.4.2 Effect of compost application on soil N status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

In Sultanönü soil no significant change in soil C:N ratio in respect to compost applications and incubation time (Figure 4.4.3). As expected the C:N ratio in Çomaklı soil tended to decrease with increasing compost rates mainly due to the enhancement in soil N by compost applications (Figure 4.4.3 and 4.4.2).

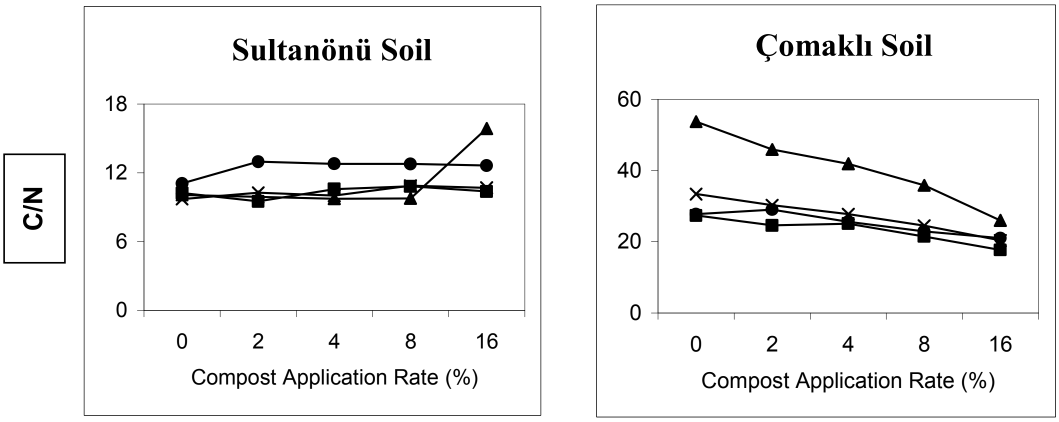


Figure 4.4.3 Effect of compost application on soil C/N status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

As it is expected, pH value of both soils decreased in time due to leaching of basic cations by irrigation (Figure 4.4.5). More importantly, compost addition decreased soil pH in both soils. For example, at the initial sampling (i.e. without incubation), soil pH was readily decreased by nearly 0.5 unit as a result of 16% compost treatment (Figure 4.4.5). The effect of incubation time together with compost treatments was more striking on soil pH. In both soils, soil pH was reduced by about 1 unit following addition of 16% compost and 3-6 month incubation time (Figure 4.4.5).

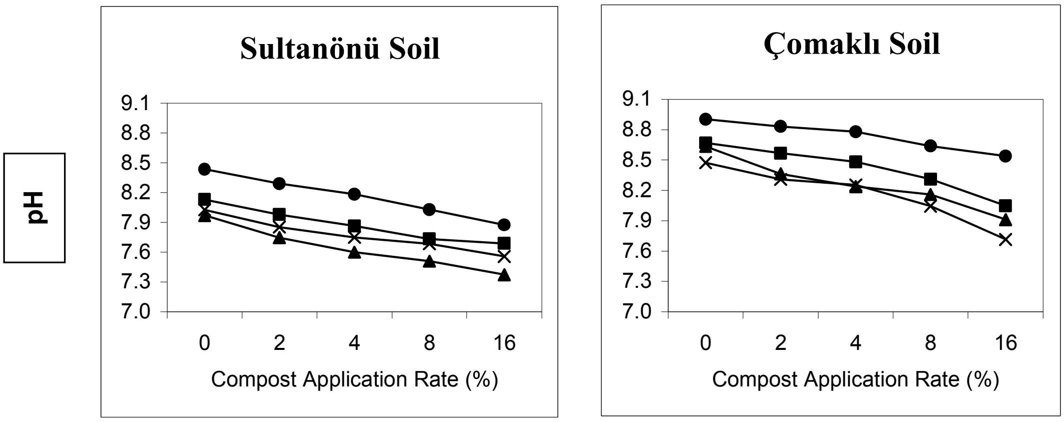


Figure 4.4.4 Effect of compost application on soil pH in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

The electrical conductivity of B-toxic Çomaklı soil and Sultanönü soil were 0.3 dS/m and 0.1 dS/m respectively. The electrical conductivity (EC) was clearly enhanced with increasing rates of compost. However, EC values were almost constant without any significant change during six months of incubation time (Figure 4.4.6).

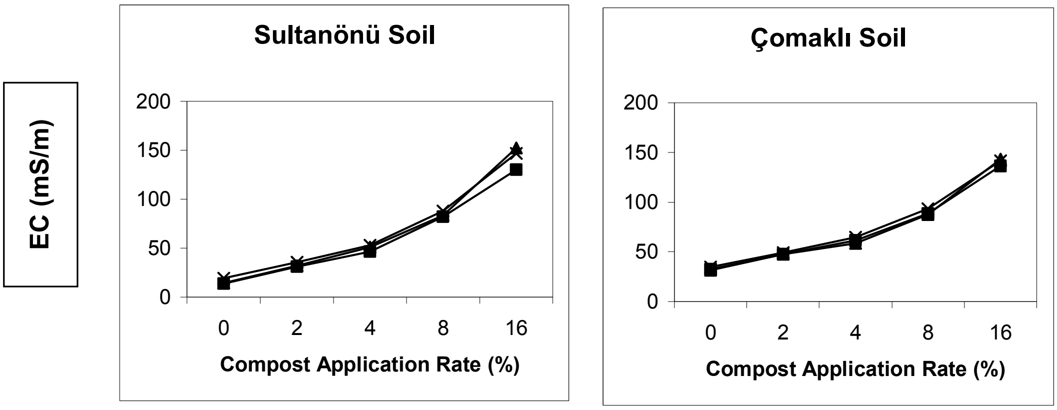


Figure 4.4.5 Effect of compost application on soil EC in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

Concentration of total soluble Cl of soils was also enhanced by compost treatments as in EC values. Soluble Cl levels were not affected with incubation time up to six months (Figure 4.4.7)

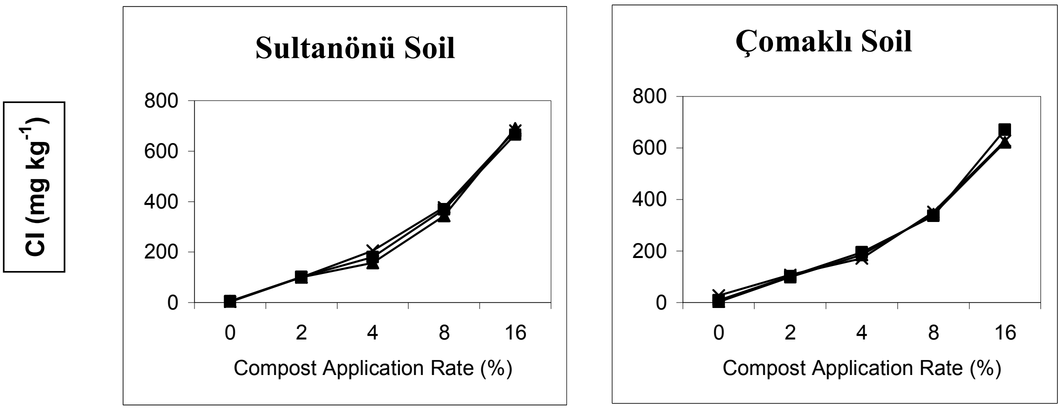


Figure 4.4.6 Effect of compost application on soil Cl status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation).

4.4.2 Effect of Incubation on Extractable Minerals

In Sultanönü soil increasing compost applications resulted in a substantial increse in mannitol extractable B concentration. The dramatic increase caused by compost applications did not change with time (Figure 4.4.4). In all compost treatments, there was no significant change in the amount of mannitol extractable B within six months of incubation period. Compost addition had no effect on mannitol extractable B in Çomakli soil. Çomaklı soil had inherently very high available B due to the well-known B toxicity problem, consequently addition of compost treatments did not result in a significant change in mannitol extractable B concentration in this specific soil (Figure 4.4.4).

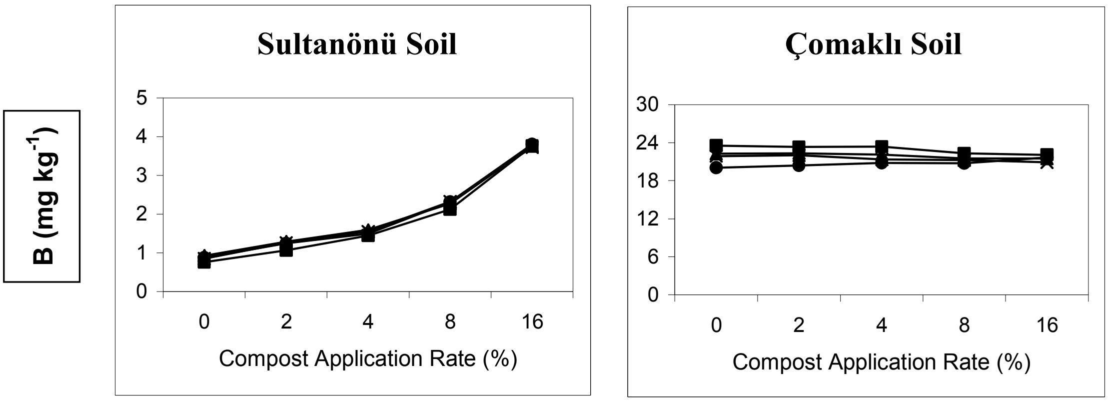


Figure 4.4.7 Effect of compost application on soil B status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

Increasing rate of compost applications enhanced DTPA extractable micro nutrients significantly (Figure 4.4.8). In both soils, DTPA extractable micro nutrient concentrations were increased in order of Zn>Cu>Fe>Mn by compost treatments (Figure 4.1.3; Figure 4.2.4; Figure 4.4.8).

There was a clear decrease in DTPA extractable concentration of Fe and Mn, Within three months of incubation time DTPA-Fe was reduced by ~50% and DTPA-Mn was reduced by ~80% in all compost treatments. However DTPA-Zn and DTPA-Cu values were much less affected in time showing only a slight decrease at the end of the incubation period (Figure 4.4.8).

Sultanönü Soil **Çomaklı Soil**

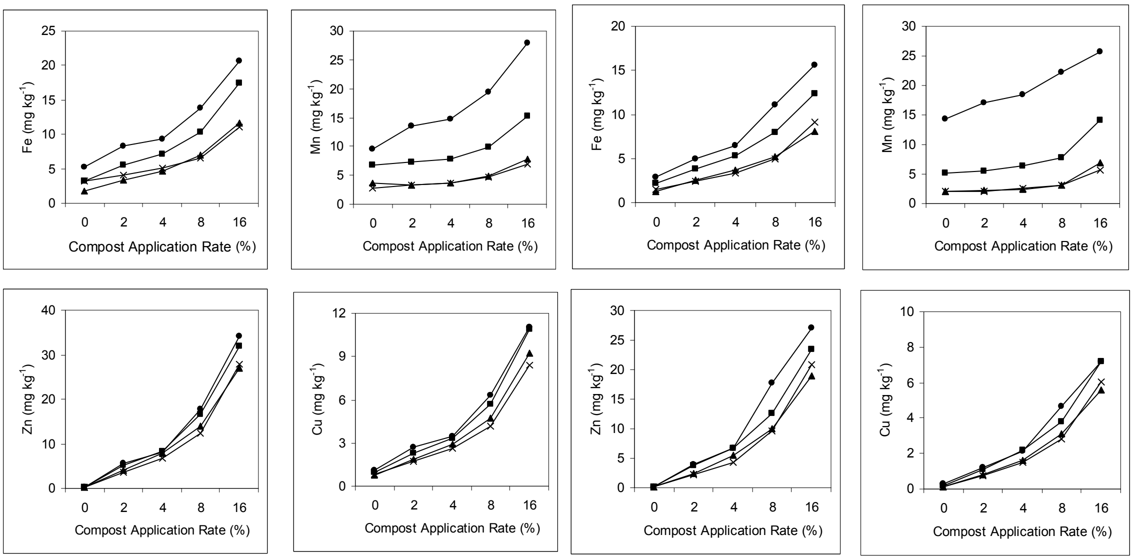
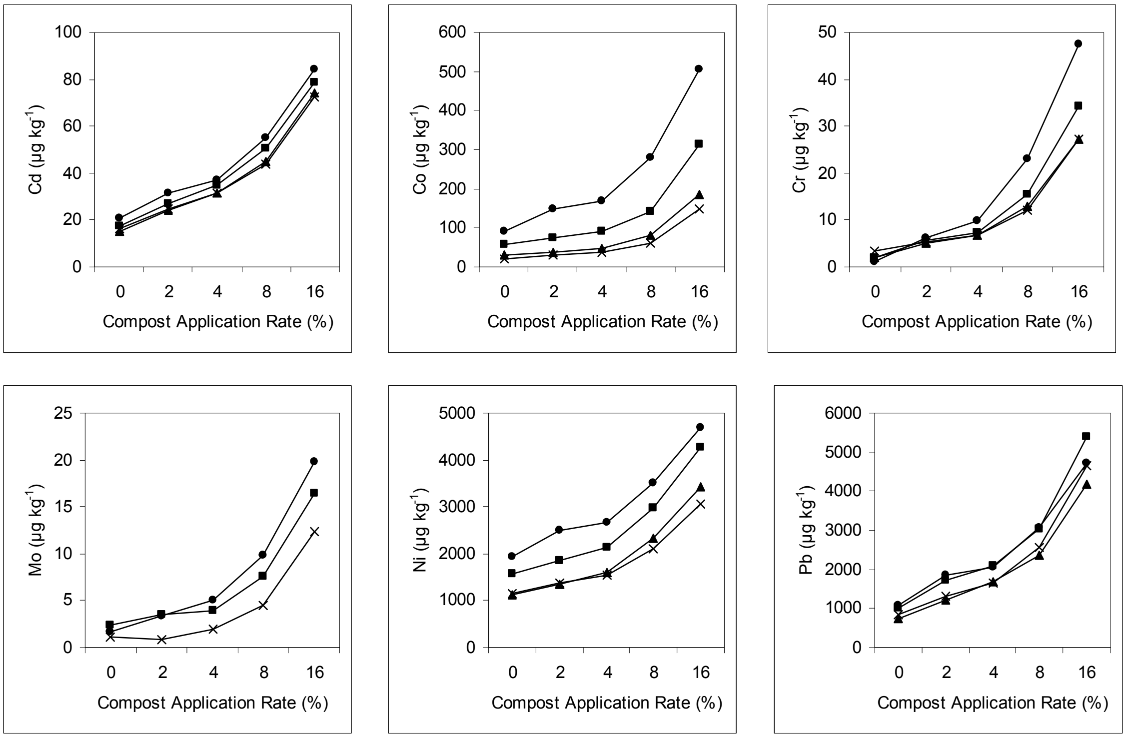


Figure 4.4.8 Effect of compost application on soil DTPA extractable micronutrient status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

Compost treatments resulted in dramatic increases in DTPA extractable concentrations of heavy metals in both soils. Soil DTPA extractable heavy metal concentrations were enhanced in the order of Cd>Pb>Cr>Mo>Ni>Co with increasing rates of compost treatments (Figure 4.4.9). Compared to Çomaklı soil, the increase in DTPA extractable heavy metals was more striking in Sultanönü soil. With incubation time, DTPA extractable amount of heavy metals slightly decreased particularly in Co, Ni, Mo and Cr (Figure 4.4.9).

Sultanönü Soil



Çomaklı Soil

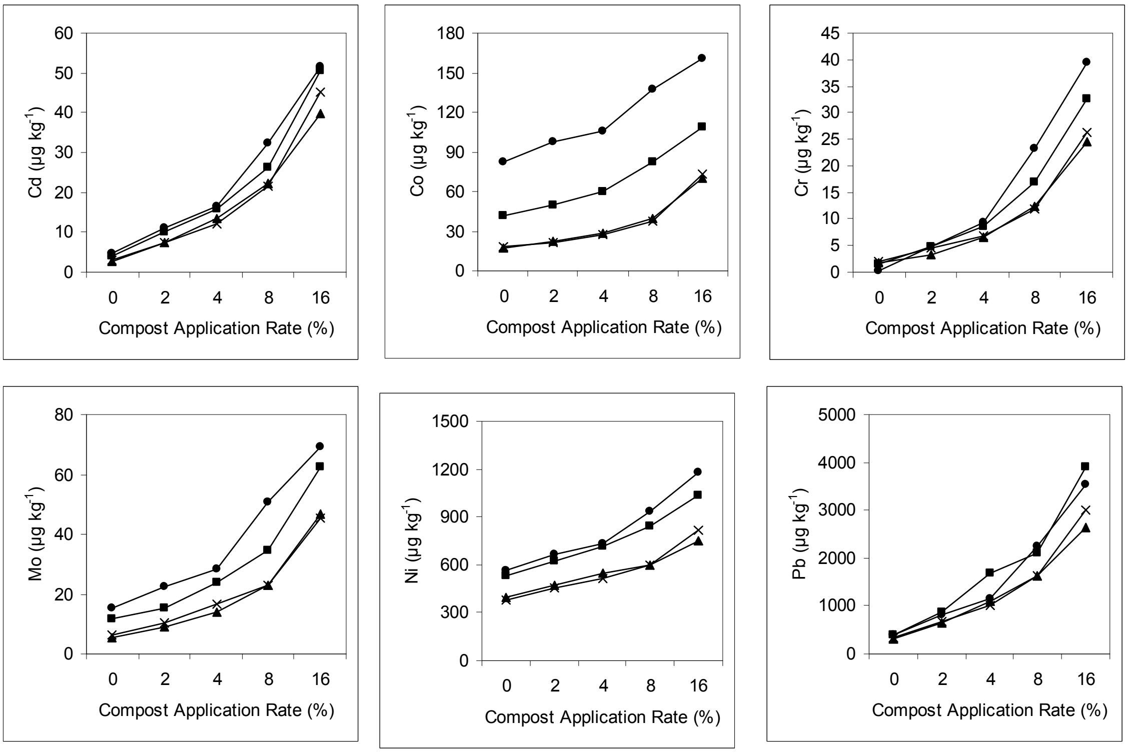
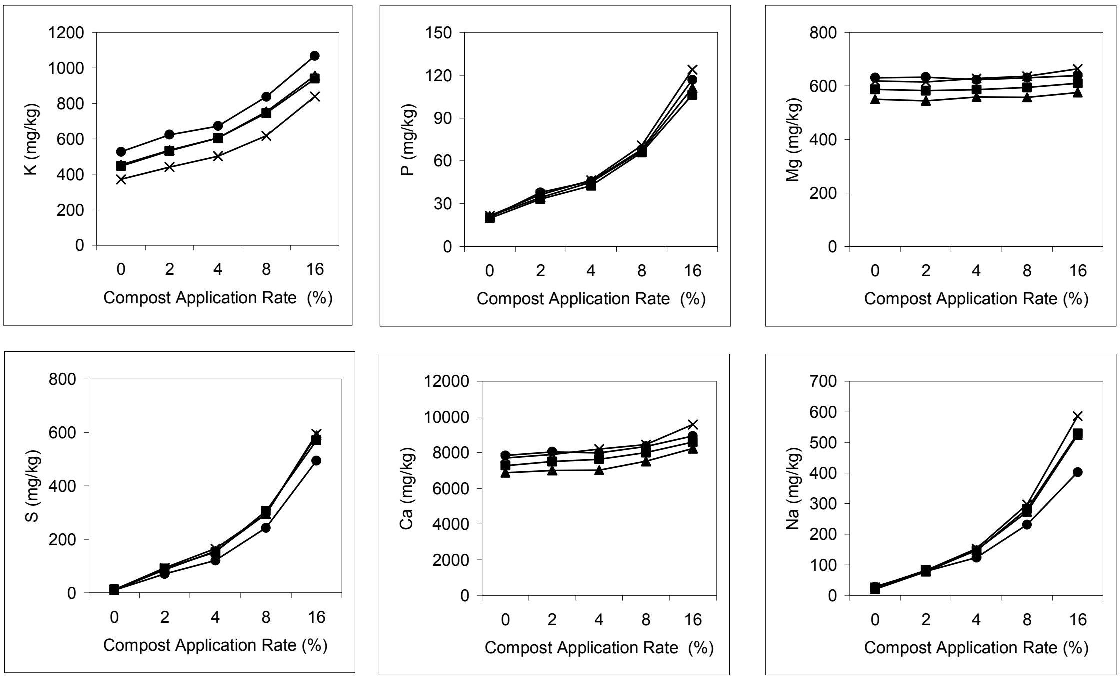


Figure 4.4.9 Effect of compost application on DTPA-extractable heavy metal status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

According to Mehlich-III extraction results, availability of macronutrients were influenced by compost addition to soil in the order of S>P>K in both soils. However, concentration of Mehlich-III extractable Mg and Ca was not significantly affected by compost treatments. In both soils there was a clear decrease in available K concentration with duration of time. Opposite to this finding, Mehlich-III extractable P values were slightly increased at the end of incubation period (Figure 4.4.10). As it was expected, soil extractable Na concentrations increased dramatically with increasing compost applications.

Sultanönü Soil



Çomaklı Soil

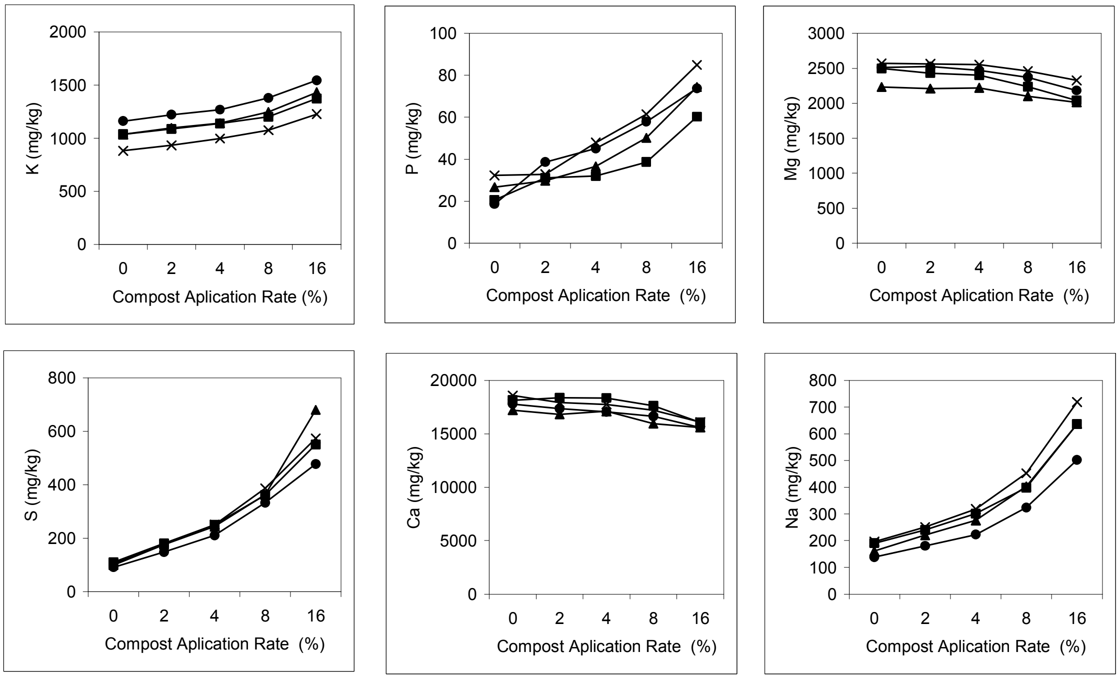
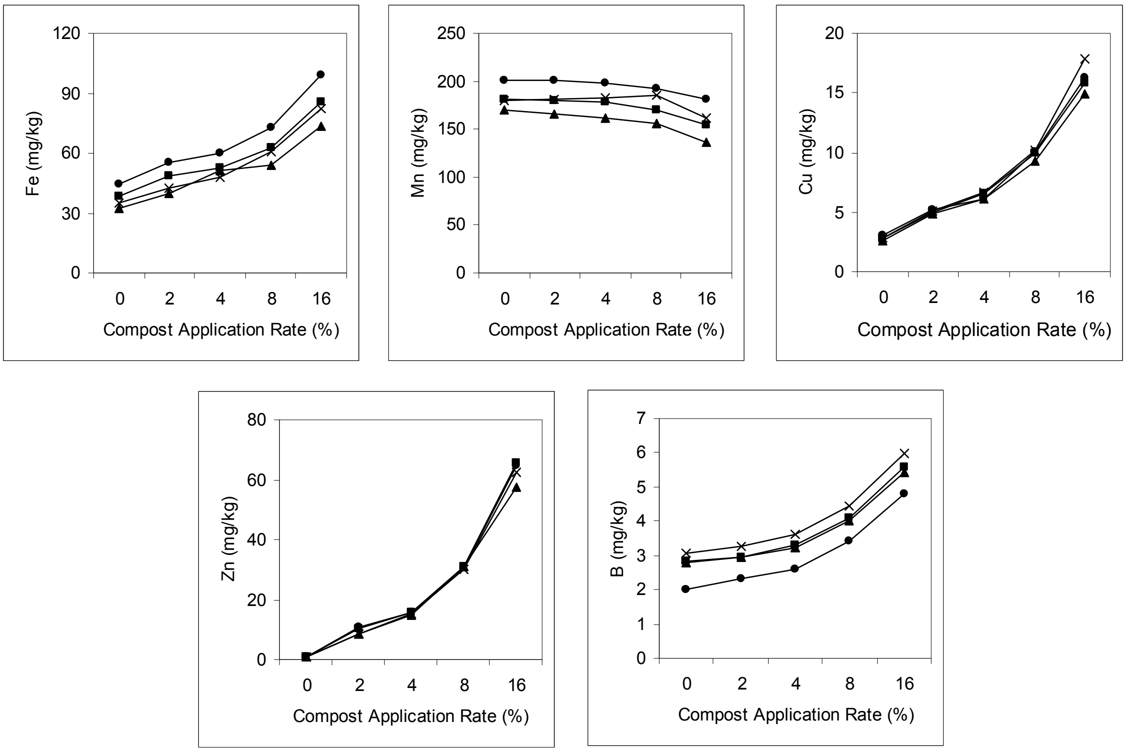


Figure 4.4.10 Effect of compost application on Mehlich-III extractable macronutrient status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)..

With increasing rates of compost application to soil, Mehlich-III extractable micronutrient concentrations were inclined dramatically in the order of Zn>Cu>Fe (Figure 4.4.11). This finding was in line with DTPA extraction; however Mehlich-III extractable Mn values were not similar with DTPA extraction values (Figure 4.4.11 and 4.4.8). In Sultanönü soil, Mehlich-III-Mn was gradually reduced with compost applications. Accordingly Mehlich-III-Mn results are supported by plant tissue analysis (see greenhouse results), whereas DTPA-Mn results do not represent realistic values at least for Sultanönü soil applied with compost.

Sultanönü Soil



Çomaklı Soil

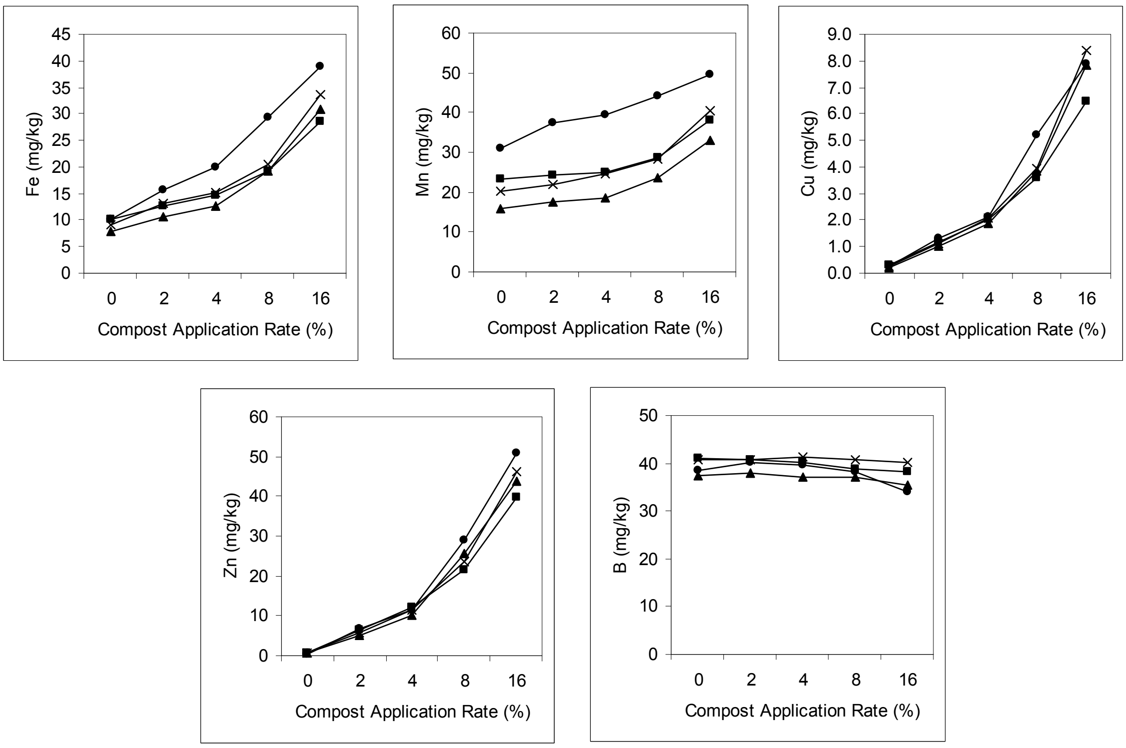
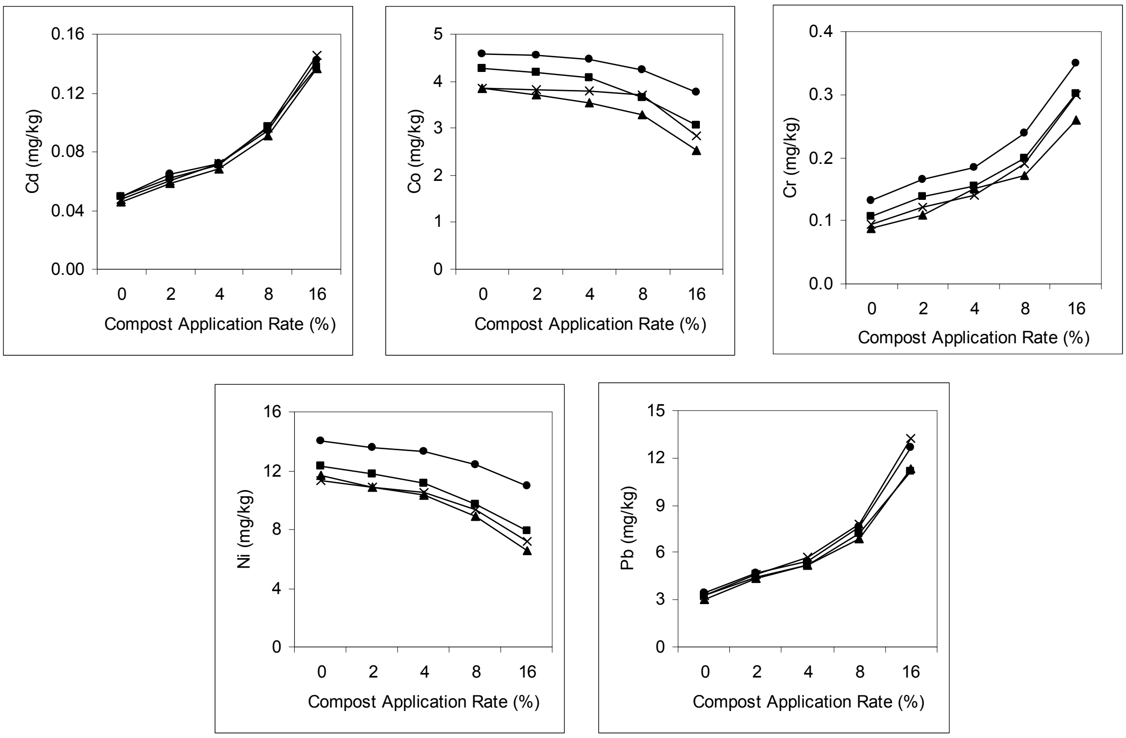


Figure 4.4.11 Effect of compost application on Mehlich-III extractable micronutrient status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation)...

Mehlich-III extractable heavy metals of incubation soils are provided in Figure 4.4.12. The potential toxic metals Cd and Pb similarly enhanced upon compost treatments in both soils and in both extraction methods. (Figure 4.4.12 and 4.4.9). According to both extraction methods, Cd and Pb concentrations were increased by 4-6 fold with compost applications. Unfortunately, there was no evident change in Mehlich-III extractable concentration of Cd and Pb with duration of time. Mehlich-III extractable Cr was also increased up to three fold, particularly in Sultanönü soil. Interestingly Mehlich-III extractable Co and Ni concentration of control soil was about 20 fold higher in Sultanönü compared to Çomaklı. Compost addition resulted in reduction of Mehlich-III extractable Co and Ni values in Sultanönü soil but not in Çomaklı soil. This finding was also in conflict with DTPA results in which all heavy metals increased upon compost treatments (Figure 4.4.12 and 4.4.9).

Sultanönü Soil



Çomaklı Soil

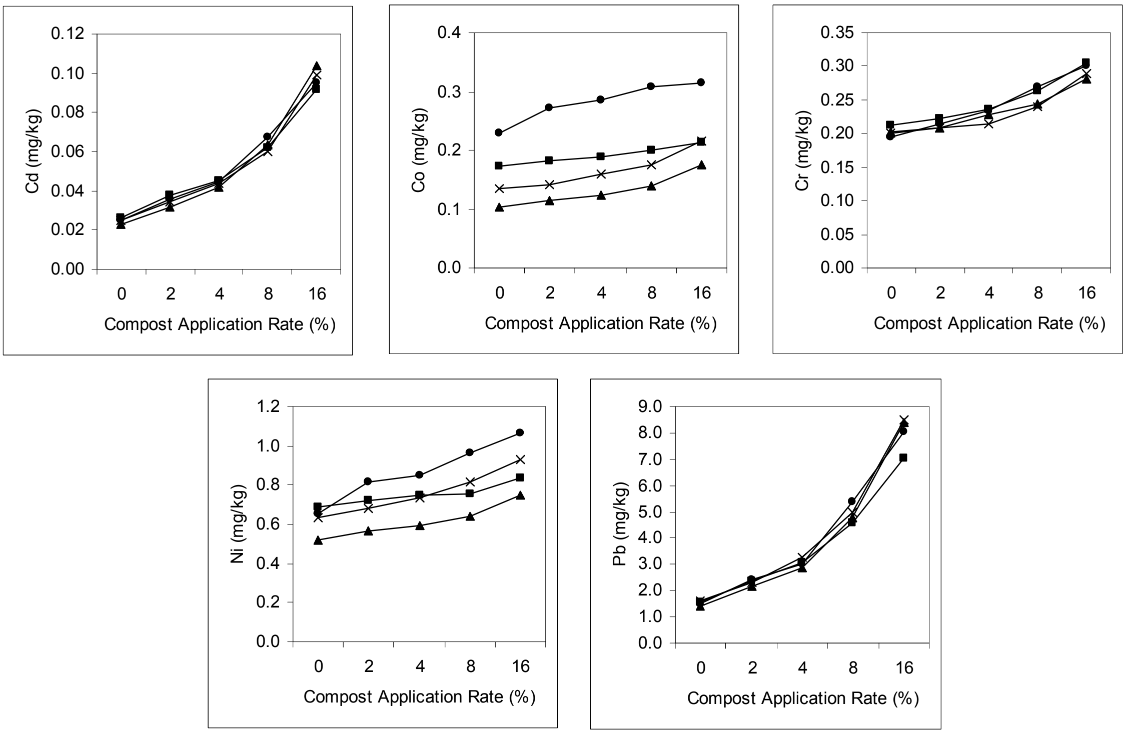


Figure 4.4.12 Effect of compost application on Mehlich-III extractable heavy metal status in Sultanönü (Zn-deficient) and Çomaklı (B-toxic) soils incubated under greenhouse conditions for six months (●: at the beginning of the incubation, ■: 1. month incubation, ▲: 3. month incubation, **X**: 6.month incubation).

5 DISCUSSION

4.5 Effect of MSW Compost on Soil Chemical Properties

The effect of compost application on soil quality has been studied for many decades. Compost amendments to acidic soils can increases the pH of the soil whereas a slight decrease may occur when added to alkaline soils (Hernanado *et al*., 1989; Mays *et al*., 1973; Mays and Giordano 1989; Hortenstine and Rothwell, 1973; King *et al*., 1977). In the present study, effect of İSTAÇ A.Ş. MSW compost product on soil chemical properties was evaluated using two different alkaline soils. The pH of both soils decreased 0.5 to 1.0 units when amended with high compost rates and duration of time. The effect of compost on soil pH can be considered as an added value because availability of mineral nutrients, particularly P, Fe, and Zn is enhanced by a decrease in pH in alkaline soils (Marschner, 1995).

There is a consensus in the literature that MSW compost amendments increase soil electrical conductivity (EC), a parameter used to determine total soluble salt content of soils (Hortenstine and Rothwell, 1972; Manios and Syminis, 1988; Fiskell and Pritchett, 1980; Chanysak *et al*., 1982). The compost product used in the present study severely enhanced soil EC values in two different alkaline soils. Due to the pronounced effect on soluble Cl and extractable Na values of soils, the main source of soluble salts in the compost product is suggested to be NaCl. Compost applications were so effective in increasing soil EC that at high compost rates (i.e. 16%) soil EC was increased nearly to “slightly saline” conditions.

In order to observe the effect of compost on soil macro and micro element concentrations, DTPA and Mehlich-III extraction methods were used in combination. The Mehlich III method was developed by Mehlich in 1984 for routine soil tests to estimate the amount of plant available soil nutrients (Mehlich, 1984). Mehlich-III soil extraction is becoming more popular every day because it allows analyzing macro and micro nutrients simultaneously by new generation ICP-AES instruments in a single extraction. The DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method is used for estimating the potential soil availability of Zn, Cu, Mn, Fe as well as heavy metals such as Cd, Ni and Pb (Lindsay and Norvell, 1978).

Among the plant macronutrients compost amendments mainly enhanced P, K, and S concentrations as judged by plant and soil analysis. This finding is in well agreement with the published literature. Giusquiani *et al.* showed that even low rates of compost applications increased soil K concentrations (Giusquiani *et al.*, 1988). Moreover, a high percent of the total K in MSW compost was suggested to be in plant available form (deHaan, 1981; Soumare *et al.*, 2003). Many studies showed that soil Ca, S, and Mg concentrations increased with MSW compost applications (Maynard, 1995; Warman *et al.*, 2004; Zhang *et al.*, 2006). However, in the present study, Mehlich-III extracted Mg and Ca concentrations did not show significant changes with compost treatments in correlation with the crop response. It seems that in İSTAÇ A.Ş. compost, Mg and Ca are not in a form that the plants can easily access and utilize.

Concerning the effect of compost applications on micro nutrients, soil analysis with DTPA and Mehlich-III extractions and plant responses (shoot elemental analysis) showed consistency with regard to Zn, Fe, and Cu concentrations. The most distinct effect of compost treatments was the dramatic enhancement of Zn nutrition of plants. This was further confirmed by soil analysis. Mehlich-III and DTPA extraction methods showed a gradual increase in plant available Zn in soil by compost applications. Soil DTPA-Zn was increased from 0.3 mg kg^{-1} to 1.5 mg kg^{-1} with chemical Zn fertilization. In the case of 2% compost application DTPA-Zn was enhanced to 5.7 mg kg^{-1}. With regard to Zn enhancement, 2% compost treatment responded much better than chemical Zn application (Figure 4.4.11). Briefly, both extraction methods confirmed the positive effect of compost application on Zn uptake of plants. Moreover, both methods showed increases on soil bioavailable Fe and Cu levels with compost treatments. Likewise, these microelements increased with compost in plant shoot. Many authors suggest that total and extractable Cu concentrations showed an increase in soils treated with MSW compost (Warman *et al.*, 2004; Zheljazkov and Warman, 2004; Zhang *et al.*, 2006). Others indicate that, low rates of compost applications have no effect on plant available Cu due to its unavailable form in the compost (Giusquiani *et al.*, 1988; Zheljazkov and Warman, 2004). The present research pointed out that MSW compost produced by İSTAÇ A.Ş. is rich in plant available Zn, Cu, and Fe. The mobility of B in compost is reported to be high and high application rates can result in B toxicity in sensitive plant species (He *et al.*, 1995). Confirming this, both soil (Mehlich-III and mannitol extraction) and plant analysis results showed that plant available B concentration was enhanced in Sultanönü soil upon compost treatment. Interestingly shoot B concentrations were reduced by compost amendment to Comkali soil with B toxicity problem. Compost seems to have a unique property of B adsorption when concentration of B in soil solution is above the critical toxicity level. According to the literature Mn in compost product is mostly found in unavailable forms for plant uptake (Zheljazkov and Warman, 2004). Results from greenhouse experiments also showed a negative relation between Mn nutrition and compost applications. Also soil Mehlich-III analysis confirmed this finding in Sultanönü soil, however DTPA results did not provide realistic results for Mn.

There is a general concern about the heavy metal content of MSW composts that application to agricultural lands may lead to serious environmental pollution and health problems (Epstein *et al.*, 1992). According to greenhouse experiments, compost addition only had a significant effect on shoot Cd and to some extent Pb levels. Plant analysis results were in agreement with DTPA and Mehlich-III extractions for Cd and Pb and methods correlated well with each other. According to both extraction methods, Cd and Pb concentrations showed dramatic increases in compost treated soils. Nevertheless, DTPA and Mehlich-III extraction methods showed significant differences for Co, Ni, and Cr concentrations. When plant heavy metal concentrations were compared with DTPA and Mehlich-III extraction results, Mehlich-III supplied more realistic values than DPTA for heavy metals. Accordingly it is proposed that Mehlich-III extraction method should be used instead of DTPA extraction method for soils treated with MSW composts. However, Mehlich-III values should be evaluated with on-site calibration experiments along with classical DTPA extraction and plant analysis results because there is no published literature data for heavy metal limit values for Mehlich-III method.

In summary ISTAÇ A.Ş. MSW compost had positive effects on soil chemical properties such as pH, organic matter, and macro and micro element concentrations. However, results also suggest that very high rates and prolonged use of compost applications may lead to salt toxicity and accumulation of Cd and Pb in soils.

4.6 Effect of MSW Compost on Plant Growth, Mineral Nutrition and Heavy Metal Accumulation

Results of greenhouse pot experiments indicate a promoting effect of compost on shoot dry matter production, particularly under low soil fertility such as insufficient basal fertilization or Zn deficiency. There are various reports concluding that the yield of agronomic crops can be increased with compost treatments (Kuo *et al*., 2004 and the references therein). However, as a general rule, very high MSW compost rates may inhibit plant growth due to potentially toxic substances such as high salts, heavy metals and organic pollutants. Since compost quality shows significant differences depending on the composition of the raw material and composting process, the appropriate application dose varies from one research to another. Therefore, individual studies are necessary to find the best application rate for a given compost product. This situation is also reflected in the literature data with confounding recommended rates for compost applications: in one research paper it was stated that MSW compost application rate should not exceed 15 t ha^{-1} (Lima *et al*., 2004), however others reported no negative effect on crop growth and nutrition when plants were grown with 64 t ha^{-1} compost supply (Hortenstine *et al*., 1973). In the present study, compost applications up to 10% (w/w) rate had positive effects on lettuce dry matter production. In the case of grass species, compost application did not have significant contribution to dry matter yield. In the case of wheat, 10% compost application caused a pronounced decrease in shoot dry matter yield. In Zn-deficient and B-toxic soils, increasing rate of compost applications had positive effects on shoot biomass production, particularly at 0% and 33% basal fertilizer rates. Even at the highest compost application rate (16%) with sufficient fertilizer treatment, dry matter yield of wheat plants did not decrease below the untreated (control) plants.

In general compost is accepted to be a good soil conditioner improving soil physical properties and providing mineral nutrients to plants and soil. Various studies showed an increase in shoot P, K, S, Zn, B, Cu uptake with compost applications (Hargreaves *et al*., 2007 and the references therein) and thus affecting plant growth.

It is well-known that MSW composts are generally high in salt content. The MSW compost produced by İSTAÇ A.Ş. has high levels of Na and Cl. Consequently, high application rates (i.e. >8%) resulted in accumulation of Na and Cl in soil and plant shoots. In the present study, tip burn and necrosis relating to salt toxicity were observed in wheat plants receiving 16% compost treatment. Similarly, lettuce plants exhibited typical salt toxicity symptoms when 10% compost was applied. It is concluded that application rate of İSTAÇ A.Ş. MSW compost product should not exceed 3% (or 112 t ha^{-1}) for sensitive plants. In timothy and red clover, the amount of Na taken up and transferred to the shoots was significantly increased at 90 t ha^{-1} compost (Zheljazkov *et al*., 2006). Similarly, Na uptake was significantly increased in spinach when MSW compost was applied at increasing rates up to 80 t ha^{-1} (Maftoun *et al*., 2004). Addition of zeolite clearly stabilized excess Na in the compost, therefore zeolite can be a good additive for İSTAÇ A.Ş. compost product when considered to apply salt sensitive plants. Conversely, as vinasse addition to compost increased Na uptake of plants, it can not be an additive for improving compost quality.

The most attractive results among micronutrients have been seen on plant Zn and B concentrations. Many studies showed that total soil Zn concentrations increased with MSW compost additions when compared to unamended controls (Giusquiani *et al*., 1988; Pinamonti *et al*., 1999; Walter *et al*., 2006; Zhang *et al*., 2006). The soils used in the present study were Zn-deficient and Zn concentrations of wheat plants grown on these soils were between 6 and 10 mg kg^{-1} showing severe Zn deficiency (i.e. <15 mg Zn kg^{-1}) when grown without Zn or compost applications. It was shown that the lowest compost rate used in pot experiments (i.e. 2%) was enough to correct Zn deficiency problem in the soil. This result indicates that Zn in compost is found as plant available form and compost applications effectively increase soil Zn in calcareous soils wiyh Zn deficiency problem. In the case of B, He *et. al*. suggested that compost may provide B for crops grown on B-deficient soils while high application rates may cause B phytotoxicity because of high mobility of this nutrient in compost (He *et al*., 1995). According to results produced in our study effect of compost on B availability was dependent on B status of the soil. For example in Sultanönü compost amendments contributed to B nutrition of plants, however in B-toxic Çomaklı soil B uptake was reduced to safer limits with compost treatments. These results pointed out that compost application can have multiple benefits on problematic soils as shown by using inherently Zn-deficient and B-toxic soils. In the case of Mn nutrition, shoot Mn levels of wheat plants decreased with compost application. This antagonistic relationship between Mn nutrition and compost may be due to the dramatic increase in Mn-oxidizing bacteria population found in rhizosphere.

The effect of compost on plant heavy metal levels depends on multiple and complex factors such as the soil properties, plant species and the characteristics of the compost product in question. While the increase in plant Zn, Cu, and Pb concentrations have often been observed with compost applications, the increase of Cd, Ni and Cr showed less consistency (Hargreaves *et al.*, 2008). According to our results, heavy metal accumulation in lettuce was much more than other species. This situation originated mainly because of the differences between metal bioavailability and metal absorption affinities within species. The decrease of shoot Cr and Co concentrations of lettuce was thought to be due to the ligand formation of these metals with compost and subsequent decrease in free ionic activities of these metals in the soil solution. Greenhouse experiment showed that among heavy metals, only shoot Cd concentration was significantly affected by compost applications. In all experiments and within all compost rates up to 16%, shoot Cd concentrations were found below the limits (i.e. 0.2 mg kg^{-1}) of FAO-WHO (Codex Alimentarius CODEX STAN 248-2005) and EU (COMMISSION REGULATION (EC) No 466/2001) food standards.

6 CONCLUSION

The present study has demonstrated a positive impact of Istanbul metropolitan municipality compost product on plant growth particularly in the case of low fertility conditions such as insufficient basal NPK fertilization or in problematic soils with inherent Zn deficiency and/or B toxicity problems. Using Zn-deficient and B-toxic soils, it was demonstrated that compost applications can totally eliminate Zn deficiency and decrease accumulation of B to safer limits in plant shoots. Under low fertility conditions, increasing rates of MSW compost enhanced dry matter production in lettuce, maize, wheat, and grass species. Moreover, compost applications enhanced shoot macro and micronutrient concentrations in all the plant species tested. The compost used in the present study was highly effective in alleviating Zn deficiency when applied to a severely Zn-deficient and calcareous soil. Application of 2% compost was shown to be sufficient to correct the Zn deficiency problem. Compost application had double benefit on plant B status. At low B conditions compost treatments contributed to B nutrition of plants, while in B-toxic soil high rates of compost applications reduced B uptake of plants to safer limits. Therefore, it is suggested that the compost product of Istanbul municipality can be beneficial in both B-deficient and B-toxic soils.

Results from greenhouse experiments indicate that compost application alone can not be sufficient to achieve highest yield potential without basal mineral fertilization, however highest dry matter yields could be achieved when compost and basal fertilizers were used in combination. Clearly, the MSW compost product of Istanbul metropolitan municipality was beneficial in plant production by providing essential macro and micro nutrients to plants in the order of S≥N>K>P and Zn>>Cu≥B>Fe respectively.

When applied at extremely high rates (i.e. >200 t ha^{-1}), the MSW compost product resulted in reduction of shoot biomass production due to elevated Na concentration of shoots exceeding the critical limit for cereals (i.e. >0.35%). However, occurrence of salt toxicity at excessive compost rates could be alleviated to a certain extent by zeolite amendment during the composting process. Among the heavy metals in the compost product, only Cd and Pb seem to be a concern for plant production, because shoot Cd and Pb were slightly increased at very high application rates.

It is concluded that MSW compost produced by Istanbul metropolitan municipality can be beneficial in agricultural production with some limitations. Although it was shown to enhance plant biomass production particularly at suboptimal soil conditions such as low basal fertilization, Zn-deficiency or B-toxicity, there is the need for on-site and long-term field trials to acquire cost-benefit relations and ensure safe heavy metal limits in harvested plant parts.

7 REFERENCES

1. Williams PT (1998) Waste. In: Waste Treatment and Disposal pp. 53-54. John Wiley & Sons, England.

2. Otten L (2001) Wet-dry composting of organic municipal solid waste: current status in Canada. Can. J. Civil Eng 28:124-130.

3. Barreira LP, Junior AP, Rodrigues MS, Tenório JAS (2007) Physical analyses of compost from composting plants in Brazil. Waste Management 28(8):1417-1422.

4. Eriksen G, Coale F, Bollero (1999) Soil nitrogen dynamics and maize production in municipal solid waste amended soil. Agron. J. 91:1009-1016.

5. Renkow M, and Rubin AR (1998) Does municipal solid waste composting make economic sense? Journal of Environmental Management 53:339-347.

6. Cooperband L (2002) The art and science of composting: A resource for farmers and compost producers. University of Wisconsin-Madison, Center for Integrated Agricultural Systems. www.cias.wisc.edu/pdf/artofcompost.pdf.

7. Kuo S, Ortiz-Escobar ME, Hue NV, Hummel RL (2004) Composting and compost utilization for agronomic crops and container crops. Recent Res. Devel. Environ. Biol. 1:451-513.

8. Gray KR, Biddlestone AJ (1980) Agricultural use of composted town refuse. In: Inorganic Pollution and Agriculture, pp. 313-316 Ministry of Agriculture, Fisheries and Food, Reference Book 326, London, UK.

9. de Bertoldi M (1999) The control of the process and compost quality. In: Bidlingmaier W, de Bertoldi M, Diaz L, Papaddimitriou FK, editors. Organic recovery and biological treatment pp 47-53. Berlin: Rhombos.

10. Gruneklee CE (1997) Development of composting in Germany. In: Stentiford EI, editor. Organic Recovery and Biological Treatment into the Next Millennium. Orbit 97 Conference Proceedings. pp.313-316. Harrogate, UK.

11. DHV (1997) Composting in the European Union. Final report. European Commission, DGXI.

12. Slater RA, and Frederickson J (2001) Composting municipal waste in the UK: some lessons from Europe. Resources, Conservation and Recycling 32:359-374.

13. Epstein E, Chaney RL, Henrys C, Locans TJ (1992) Trace elements in municipal solid waste compost. Biomass and Bioenergy 3:227-238.

14. Lima JS, de Queiroz JEG, Freitas HB (2004) Effect of non-selected urban waste compost on the initial growth of corn. Resources, Conservation and Recycling 42:309-315.

15. Sabo A, and Ferrini F (2006) The use of compost in urban areas- A review for practical application. Urban forestry & urban greening 4:159-169.

16. Altinbas M, Gencsoy EB, Ciftci DI, Arıkan OA, Demir I, Ozturk L, Yıldız S, Ciftci T, Cakmak I, Ozturk I (2007) Full-Scale Aerobic Composting of Municipal Solid Waste of Istanbul Metropolitan. In: The 2nd project development report of the research project of the applicability of MSW compost produced by Istanbul Metropolitan Municipality on plant cultivation as fertilizer, pp. 59-68, Istanbul, Turkey.

17. Hargreaves JC, Adl MS, Warman PR (2008) A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems and Environment 123:1-14.

18. Gomez A (1998) The evaluation of compost quality. Trends in analytical chemistry, 17(5):310-314.

19. Cooperband LR (2000) Composting: Art and science of organic waste conversion to a valuable soil resource. Laboratory Medicine 31:283-290.

20. Walker P, Williams D, Waliczek TM (2006) An analysis of the horticulture industry as a potential value added market for compost. Compost Science & Utilization 14(1)23:31.
21. Urban J (1998) Simplified soil testing. In: Neely D, Watson G (Eds.) The Landscape Below Ground II. Proceedings of an International Workshop on Tree Root Development in Urban Soils. International Society Arboriculture, Champain, IL, pp. 141-145.

22. Obreza TA, Webb RG, Biggs RH (1989). Humate materials: their effects and use as soil amendments. The Citrus Industry

23. Amlinger F, Gotz B, Dreher P, Geszti J, Weissteiner C (2003) Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability– a review. European Journal of Soil Biology 39:107–116.

24. Dumontet S, Dinel H, Baloda SB (1999). Pathogen reduction in sewage sludge by composting and other biological treatments: a review. Biological Agriculture and Horticulture 16(4):409–430.

25. Fichtner EJ, Benson DM, Diab HG, Shew HD (2004) Abiotic and biological suppression of *Phytophtora parasitica* in a horticultural medium containing composted swine waste. Phytopathology 94:780–788.

26. Amlinger F, Favoino E, Pollak M (2004) Heavy metals and organic compounds from wastes used as organic fertilisers (ENV.a.2./etu/2001/0024) on behalf of the EU Commission DG ENV.

27. OMRI (1998) Organic Materials Review Institute. Draft Standards, Compost Quality. Manuscript.Eugene Oregon.

28. Silva MTB, Menduíña AM, Seijo YC, Viqueira FC (2007) Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media, Waste Manage Res 25: 99–108.

29. U. S. Environmental Protection Agency (1989) Standards for the Disposal of Sewage Sludge; Proposed Rules. 40 CFR Parts 257 and 503. Federal Register 54:5746-5902.

30. Brinton WF (2000) Compost Quality Standards & Guidelines. An International View. Woods End Research Laboratory, available at www.cfe.cornell.edu/wmi/Compost/.

31. Hogg D, Barth J, Favoino E, Centemero M, Caimi V, Amlinger F, Devliegher W, Brinton W, Antler S (2002) Comparison of compost standards within the EU, North America and Australasia. The Waste and Resources Action Programme Committee (UK), www.wrap.org.uk, ISBN 1-84405-004-1.

32. TKKY: Toprak Kirliliğinin Kontrolü Yönetmeliği, Çevre ve Orman Bakanlığı, Resmi Gazete Tarihi: 31/05/2005, Resmi Gazete Sayısı : 25831.

33. Kraus P, and Grammel U (1992). Relevance of contaminant discussion for bio-waste composting, as reported in Brinton WF (2000). "Compost quality standards & guidelines: An International View." New York State Association of Recyclers.

34. Wiemer K, and Kern M (eds) (1989) Kompostierung International (Compost International), Abfall Wirtschaft, (Technical Series) No:2, pp.400, University of Kassel, MIC Baeza Verlag.

35. He X, Logan T, Traina S (1995) Physical and chemical characteristics of selected U.S. municipal solid waste composts. J. Environ. Qual. 24:543–552.

36. He X, Traina SJ, Logan TJ (1992) Chemical Properties of Municipal Solid Waste Composts. J Environ Qual 21: 318-329.

37. Zheljazkov DZ, and Warman PR (2004) Source-Separated Municipal Solid Waste Compost Application to Swiss Chard and Basil. J. Environ. Qual. 33:542-552.

38. Angelidis M, Gibbs RJ (1988) Chemistry of metals in anaerobically treated sludges. Water Res. 23:29-33.

39. Rudd T, Campbell JA, Lester JN (1988) The use of model compounds to elucidate metal forms in sewage sludge. Environ. Pollut. 50:225-242.

40. Brennan B (1991) Chemical partitioning and remobilization of heavy metals from sewage sludge dumped in Dublin Bay. Water Res. 25:1193-1198.

41. Garcia-Delgado RA, GarciaHerruzo F, Gomez-Lahoz C, Rodriguez-Maroto JM (1994) Heavy metals and disposal alternatives for an anaerobic sewage sludge. J. Environ. Sci. Health Part A 29 (7):1335-1347.

42. Zorpas AA, Constantinides T, Vlyssides AG, Haralambous I, Loizidous M (2000) Heavy metal uptake by natural zeolite and metals partitioning in sewage sludge compost. Bioresource Technology, 72(2):113-119.

43. Meissl K, Smidt E, Tintner J, Binner E, Lechner P (2008) A new analytical approach to determine compost quality. Abstract for CODIS 2008, International Congress, CH_Solothurn, 27th – 29th February 2008.

44. Garcia-Gil JC, Ceppi SB, Velasco MI, Polo A, Senesi N (2004) Long- term effects of amendment with municipal solid waste compost on the elemental and acidic functional group composition and pH-buffer capacity of soil humic acids. Geoderma. 121: 135-142.

45. Binner E, Tintner J, Meissl K, Smidt E, Lenchner P (2008) Humic Acids- A quality criterion for compost. Abstract for CODIS 2008, International Congress, CH_Solothurn, 27th – 29th February 2008.

46. Goyal S, Dhull SK, Kapoor KK (2005) Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. Bioresource and Technology 96:1584–1591.

47. de Bertoldi M, Vallini G, Pera A, Zucconi F (1982) Comparison of three windrow compost systems. Biocycle 23(2):45-50.

48. Epstein E (1997) The Science of Composting. Technomic Publishing Company, Inc., PA, USA.

49. Bar-Tal A, Yermiyahu U, Beraud J, Keinan M, Rosenberg R, Zohar D, Rosen V, Fine P (2004) Nitrogen, phosphorus, and potassium uptake by wheat and their distribution in soil following successive, annual compost applications. Journal of Environmental Quality 33:1855-1865.

50. Pickering JS, Shepherd A, 2000. Evaluation of organic landscape mulches: composition and nutrient releasecharacteristics. Arboricultural Journal 24(2/3):175-187.

51. Brady N, Weil R (1996) The Nature and Properties of Soils. 12th ed. Prentice, New Jersey, USA, pp. 385-495.

52. Hicklenton P, Rodd V, Warman PR (2001) The effectiveness and consistency of source-separated municipal solid waste and bard composts as components of container growing media. Sci. Hort. 91:365-378.

53. He X, Logan T, Traina S (1995) Physical and chemical characteristics of selected U.S. municipal solid waste composts. J. Environ. Qual. 24:543–552.

54. Warman PR and Rodd V (1998) Influence of source-separated MSW compost on vegetable crop growth and soil properties: year 3. In: Proceedings of the 8th Annual Meeting of the Composting Council of Canada, Ottawa, Ontario, pp. 263–273.

55. Warman PR (2001) Municipal solid waste compost effects tomato leaf tissue: essential plant nutrients and trace elements. In: Proceedings of the 6th International Conference on the Biogeochemistry of Trace Elements, Guelph, p. 167.

56. Warman PR, Murphy C, Burnham J, Eaton L (2004) Soil and plant response to MSW compost applications on lowbush blueberry fields in 2000 and 2001. Small Fruit Rev. 3(1/2):19-31.

57. Garcia-Gil JC, Plaza C, Soler-Rovira P, Polo A (2000) Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biol. Biochem. 32:1907-1913.

58. TMECC 2001 Test Methods for the Examination of Composting and Compost. US Composting Council & USDA, 05.02-F Agricultural Index.

59. Brady NC (1990) The Nature and Properties of Soils, (10th Edition), MacMillan, London, UK.

60. Deiana S, Gessa C, Manunza B, Rausa R, Sebeer R (1990) Analytical and spectroscopic characterization of humic acids extracted from sewage sludge, manure and worm compost. Soil Sci. 150 (1):419-426.

61. Giusquiani PL, Gigliotti G, Businelli D (1992) Mobility of heavy metals in urban waste-amended soils. Journal of Environmental Quality 21:330-335.

62. Martens DA, Johanson JB, Frankenberger WT (1992) Production and persistence of soil enzymes with repeated addition of organic residues. Soil Sci 153:53-61.

63. Shiralipour A, Mcconnell DB, Smith WH (1992) Uses and benefits of MSW: a review and an assessment. Biomass and Bioenergy 3(3-4):267-279.

64. Piccolo A (2002) The supramolecular structure of humic substances: a novel understanding of humus chemistry and implications in soil science. Advances in Agronomy 75:57-134.

65. Stuckey HT and Hudak PF (2001) Effects of compost on Loblolly pine tree growth in Northeast Texas. Compost Science & Utilization 9(1):65-72.

66. Epstein E, Taylor JM, Chaney RL (1976) Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. J. Environ. Qual. 5(4):422-426.,

67. Mays DA, Terman GL, Duggan JC (1973) Municipal compost: effects on crop yields and soil properties. J. Environ. Qual. 2(l):89-92.

68. Pagliai M, Guidi G, LaMarca M, Giachetti M, Luccamante G (1981) Effect of sewage sludges and composts on soil porosity and aggregation. J. Environ. Qual. 10(4):556-561.

69. Mays DA and Giordano PM (1989) Landscaping municipal waste comoost. BioCycle 30(3):37-39.

70. Hernando S, Lobo MC, Polo A (1989) Effect of the application of a municipal refuse compost on the physical and chemical properties of a soil. The Science of the Total Environment 81:589-596.

71. Annabi M, Houot S, Francou C, Poitrenaud M, LeBissonnais Y (2007) Soil aggregate stability improvement with urban compost of different maturities. Soil Sci. Soc. Am. J. 71:413-423.

72. Hortenstine CC and Rothwell DF (1973) Pelletized municipal refuse compost as a soil amendment and nutrient source for sorghum. J. Environ. Qual. 2(3):343-344.

73. King LD, Leyshon AJ, Webber LR (1977) Application of municipal refuse and liquid sewage to agricultural land. II Lysimeter study. J. Environ. Qual. 6(1): 67-71.

74. Manios VI and Syminis HI (1988) Town refuse compost of Heraklio. BioCycle 29(7):44-47.

75. Zhang M, Heaney D, Henriquez B, Solberg E, Bittner E (2006) A four-year study on influence of biosolids/MSW cocompost application in less productive soils in Alberta: nutrient dynamics. Compost Sci. Util. 14(1):68-80.

76. Wilkinson RE (2000) In:Plant-environment interactions, Marcel Dekker Inc. New York, 2nd edt, pp: 102-123.

77. Iglesias-Jimenez E, Alvarez C (1993) Apparent availability of nitrogen in composted municipal refuse. Biol. Fert. Soils 16:313-318.

78. deHaan S (1981) Results of municipal waste compost research over more than fifty years at the Institute for Soil Fertility at Haren/Groningen, the Netherlands. Neth. J. Agric. 29:49-61.

79. Soumare M, Tack F, Verloo M (2003)Characterisation of Malian and Belgian solid waste composts with respect to fertility and suitability for land application. Waste Manag. 23:517-522.

80. Giusquiani P, Marucchini C, Businelli M (1988) Chemical properties of soils amended with compost of urban waste. Plant Soil 109:73-78.

81. Maynard A (1995) Cumulative effect of annual additions of MSW compost on the yield of field-grown tomatoes. Compost Sci. Util. 3(2):47-54.

82. Murphy C, Warman PR (2001) Effect of MSW compost applications on low-bush blueberry soil and leaf tissue trace elements. In: Proceedings of the 6th International Conference on the Biogeochemistry of Trace Elements, Guelph p.166.

83. Gallardo-Lara F, Azcon M, Polo A (2006) Phytoavailability and fractions of iron and manganese in calcareous soil amended with composted urban waste. J. Environ. Sci. Health B 41:1187-1201.

84. Pinamonti F, Nicolini G, Dalpiaz A, Stringari G, Zorzi G (1999) Compost use in viticulture: effects on heavy metal levels in soil and plants. Commun. Soil Sci. Plan. 30(9-10):1531-1549.

85. Walter I, Martinez F, Cuevas G (2006) Plant and soil responses to the application of composted MSW in a degraded, semiarid shrubland in central Spain. Compost Sci. Util. 14 (2):147-154.

86. Maftoun M, Moshiri F, Karimian N, Ronaghi A (2004) Effects of two organic wastes in combination with phosphorus on growth and chemical composition of spinach and soil properties. J. Plant Nutr. 27(9):1635-1651.

87. Sommers L, Volk VV, Giordano PM, Sopper VM, Bastian R (1987) Effects of soil properties on accumulation of trace elements by crops. *In: Land Application of Sludge* (A. L. Page, T. J. Logan and J. A. Ryan, Eds), pp. 5-24. Lewis Publishers, Chelsea, MI.

88. Bhattacharyya P, Chakrabarti K, Chakraborty A (2003a) Effect of MSW compost on microbiological and biochemical soil quality indicators. Compost Sci. Util. 11(3):220-227.

89. Giusquiani PL, Pagliai M, Gigliotti G, Businelli D, Benetti A (1995) Urban Waste Compost: Effects on Physical, Chemical and Biochemical Soil Properties, J. Environ. Qual., 24:175-182.

90. Hassen A, Belguith K, Jedidi N, Cherif A, Cherif M., Boudabous A (2001) Microbial characterization during composting of municipal solid waste. Bioresour. Technol. 80:217–225.

91. Crecchio C, Curci M, Mininni R, Ricciuti P, Ruggiero P (2001) Shortterm effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. Biol. Fert. Soils 34:311-318.

92. Pascual JA, Garcia C, Hernandez T, Lerma S, Lynch JM (2002) Effectiveness of municipal waste Compost and its humic fraction in suppressing Pythium ultimum. Microbial Ecology 44:59-68.

93. Bauduin M, Delcarte E, Impens R (1987) Agronomic characterization and evaluation of two new municipal waste composts. In Compost: Production, Quality and Use (M. de Bertoldi, M. P. Ferranti et al. Eds), pp. 479-486. Elsevier Applied Science, London.

94. Paris P, Robotti A, Gavazzi C (1987) Fertilizing value and heavy metal load of some composts from urban refuse. In Compost: Production, Quality, and Use (M. De Bertoldi, M. P. Ferranti et al. Eds), pp. 643-657. Elsevier Applied Science, London.

95. Rodd A, Warman PR, Hicklenton P, Webb K (2002) Comparison of N fertilizer, source-separated municipal solid waste compost and semisolid beef manure on the nutrient concentration in boot-stage barley and wheat tissue. Can. J. Soil Sci. 82:33-43.

96. Mchabela M, Warman PR (2005) The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops, grown in a Pugwash sandy loam soil in Nova Scotia. Agric. Ecosyst. Environ. 106: 57-67.

97. Terman GL, Soileau JM, Allen SE (1973) Municipal waste compost: effects on crop yields and nutrient content in greenhouse pot experiments. J. Environ. Qual. 2(l):84-89.

98. Eyüpoğlu F (1999) Türkiye topraklarının verimlilik durumu. Toprak ve Gübre Araştırma Enstitüsü Yayınları Genel Yayın no: 220. Teknik Yayın no: T – 67. Ankara.

99. Eghball B, Binford GD, Baltensperger DD (1996) Phosphorus movement and adsorption in a soil receiving long-term manure and fertilizer application. J. Environ. Qual. 25:1339-1343.

100. Whalen JK and Chang C (2001) Phosphorus accumulation in cultivated soils from long-term annual applications of cattle feedlot manure. J. Environ. Qual. 30:229-237.

101. Mkhabela M, Warman PR (2005) The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops, grown in a Pugwash sandy loam soil in Nova Scotia. Agric. Ecosyst. Environ. 106: 57-67.

102. Shanmugam GS (2005) Soil and plant response of organic amendments on strawberry and half-high blueberry cultivars. Master's Thesis. Dalhousie University, Halifax, Nova Scotia, Canada.

103. Nogales R, Azcon M, Gallardo-Lara F (1985) Sequential sulfur availability affected by town refuse compost application, Bio. Agric. Hortic. 2(4):323-328.

104. Rynk R (1992) On-Farm Composting Handbook, NRAES-54, Ithaca, NY: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension; 1-186.

105. Hargreaves JC, Adl MS, Warman PR (2008) A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems and Environment. 123:1-14.

106. Sims JT, Kline JS (1991) Chemical fractionation and plant uptake of heavy metals in soils amended with co-composted sewage sludge. J. Environ. Qual 20:387-395.

107. Henry CL and Harrison RB (1992) Fate of trace metas in sewage sludge compost. In: Biogeochemistry of trace metals (Adriano DC, ed) pp. 195-216. Lewis Publishers, Ann Arbor, MI.

108. Gigliotti G, Businelli D, Giusquiani PL (1996) Trace metal uptake and distribution in corn grown on a 6-year urban waste compost amended soil. Agriculture Ecosystem and Environment 58:199-206.

109. Wong JWC, Li GX, Wong, MH (1996) The growth of Brassica Chinensis in heavy metal contaminated sewage sludge compost from Hong Kong. Bioresource Technology 58:309-313.

110. Pichtel J and Anderson M (1997) Trace metal bioavailability in municipal solid waste and sewage sludge composts Bioresource Technology 60:223-229.

111. Simeoni LA, Barbarick KA, Sabey BR (1984) Effect of small scale omposting of sewage sludge on heavy metal availability to plants. J. Environ. Qual. 13:264-268.

112. Warman PR, Muizelaar T, Termeer WC (1995) Bioavailability of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn from biosolids amended compost. Compost Sci. Util. 3(4):40-50.

113. Zubillaga MS, Lavado RS (2002) Heavy metal content in lettuce plants grown in biosolids compost. Comp Sci Util 10(4):363-367.

114. Bhattacharyya P, Pal R, Chakrabarti K, Chakraborty A (2004) Effect of composting on extractability and relative availability of heavy metals present in Calcutta municipal solid waste. Arch Agron Soil Sci 50:181-187.

115. Bhattacharyya P, Chakraborty A, Chakrabarti K, Tripathy S, Powell MA (2006) Copper and zinc uptake by rice and accumulation in soil amended with municipal solid waste compost, Environ Geol 49: 1064-1070.

116. Jordão CP, Nascentes CC, Fontes RLF, Ceconc PR, Pereira JL (2007) Effects of Composted Urban Solid Waste Addition on Yield and Metal Contents of Lettuce J. Braz. Chem. Soc 18(1):195-204.

117. U.S. Environmental Protection Agency (1989), Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge EPA/600/6-89/001.

118. Sanderson KC (1980) Use of sewage-refuse compost in the production of ornamental plants. HortScience 15:173-178.

119. Lumis GP and Johnson AG (1982) Boron toxicity and growth suppression of Forsythia and Thuja grown in mixes amended with municipal waste compost. HortScience 17:821-822.

120. Conover CA and Joiner JN (1966) Garbage compost as a potential soil component in production of Chrysunthemum morifolium "Yellow Delaware" and "Oregon." Proc. Fl. State Hortic. Sot. 79:424-429.

121. Chu LM and Wong MH (1987) Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge. Plant Soil 103(2):191-197.

122. Leita L and DeNobili M (1991) Water-soluble fractions of heavy metals during composting of municipal solid waste. J. Environ. Qual. 20:73-78.

123. Fiskell JGA and Pritchett WL (1980) Profile distribution of phosphate and metals in a forest soil amended with garbage compost. Proc. Soil Crop Sci. Soc. Fla. 39:23-28.

124. Chanysak V, Hirai M and Kubota H (1982) Changes of chemical components and nitrogen transformation in water extracts during composting of garbage. J. Ferment. Technol. 60(5):439-446.

125. Biswas TD and Khosla BK (1971) Building up of organic matter status of the soil and its relation to the soil physical properties. In: Proc. Int. Symp. Soil Fert. Eval. 1:841-842 New Delhi, India.

126. Mehlich A (1984) Mehlich III soil test extractant: A modification of Mehlich II extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.

127. Lindsay WL and Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42:421-428.

128. Zheljazkov V, Astatkie T, Caldwell CD, MacLeod J, Grimmett M (2006) Compost, manure, and gypsum application to timothy/red clover forage. J. Environ. Qual. 35:2410-2418.

129. Walter I, Martinez F, Cuevas G (2006) Plant and soil responses to the application of composted MSW in a degraded, semiarid shrubland in central Spain. Compost Sci. Util. 14 (2):147-154.

130. Sebastiao M, Queda A, Campos L (2000) Effect of municipal soild waste compost on potato production and heavy metal contamination in different types of soil. In: Warman PR, Taylor B (Eds.), Proceedings of the International Composting Symposium. CBA Press Inc. (Pubs.), Halifax/Dartmouth, Nova Scotia, Canada, pp.760-772.

131. Deportes I, Benoit-Guyod J, Zmirou D (1995) Hazard to man and the environment posed by the use of urban waste compost: a review. Sci. Total Environ. 172:197-222.

APPENDIX

Chemicals

All chemicals and standart solutions were supplied by Merck (Germany), SIGMA (USA), Fluka (Switzerland), Applichem (Germany) and Riedel de Häen (Germany).

Equipment

Centrifuge:	Kendro Lab. Prod., Heraeus Multifuge 3 S-R, GERMANY
Chloridemeter:	Jenway, UK
C/N Analyzer:	Leco TrueSpec, USA
Distilled water:	Millipore, Elix-S, FRANCE Millipore, MilliQ, Academic, FRANCE
EC meter:	Hanna Instruments, USA
Inductively coupled plasma-optical emission spectroscopy (ICP-OES):	Varian, Vista-Pro ccd, AUSTRALIA

Magnetic stirrer: IKA$^{®}$-WERKE, GERMANY
VELP Scientifica, Microstirrer, ITALY

Microliter Pipette: Gilson, Pipetman, FRANCE
Eppendorf, GERMANY

Microwave Digestion System: CEM MarsExpress, USA

pH Meter: Hanna Instruments, USA

Spectrophotometer: Varian Carry 300 Bio, AUSTRALIA