SOIL AND WATER ANALYSIS TECHNIQUES FOR AGRICULTURAL PRODUCTION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

NUH MARAL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CHEMISTRY

MAY 2010

Approval of the thesis:

SOIL AND WATER ANALYSIS TECHNIQUES FOR AGRICULTURAL PRODUCTION

submitted by **NUH MARAL** in partial fulfillment of the requirements for the degree of **Master of Science in Chemistry Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** ____________________

Prof. Dr. İlker Özkan
Head of Department, **Chemistry** ____________________

Prof. Dr. G. İnci Gökmen
Supervisor, **Chemistry Department, METU** ____________________

Examining Committee Members:

Prof. Dr. O.Yavuz Ataman
Chemistry Dept., METU ____________________

Prof. Dr. G. İnci Gökmen
Chemistry Dept., METU ____________________

Prof. Dr. R. Sezer Aygün
Chemistry Dept., METU ____________________

Prof. Dr. E. Hale Göktürk
Chemistry Dept., METU ____________________

Dr. Nesime Cebel
Soil Fertilizer and Water Resources Central Res. Inst. ____________________

Date: May 03, 2010

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

Name, Last name: Nuh Maral

Signature :

ABSTRACT

SOIL AND WATER ANALYSIS TECHNIQUES FOR AGRICULTURAL PRODUCTION

Maral, Nuh
M. Sc., Department of Chemistry
Supervisor: Prof. Dr. G. İnci Gökmen

May 2010, 108 pages

In Turkey, usage of increasing amounts of fertilizers and pesticides by some unconscious farmers cause soil pollution and soil infertility for the crop production. Usage of water in excessive amounts and/or in poor quality for irrigation creates problems during the plant production. So in this study, soil and water samples were analyzed by using simple and reliable techniques for the soil and water quality in laboratories of METU and Soil Fertilizer and Water Resources Central Research Institute Laboratory in Ankara. The soil and water samples were collected using the standard techniques from Ankara, Bolu, Çorum and Kırıkkale.

According to the soil test results, the textures of the soil samples are found as loam and clay loam. The total salt content of the soil samples are between 0.033 – 0.063 % (w/w), meaning they are low salinity soils (total salt less than 0.15 % w/w). The pH of the soil samples are between 7.86–8.15, they are slightly alkaline. The phosphorus concentrations of soil samples are in a range 4.95 to 35.45 P_2O_5 kg/da. Some of the soil samples have too high phosphorus content (greater than 12 P_2O_5 kg/da). The potassium content of soil samples are found between 141–286 K_2O kg/da, so the soil is efficient for crop production. Lime content of the soil samples is between 1.04–2.67 % (w/w) $CaCO_3$. It means all of the soil samples are calcareous but it is not too high for the agricultural production. Organic matter content of soil samples are found between 0.83–2.04 % (w/w). This means the soils are limited in their organic matter content for the crop production.

Analysis of 22 water samples yielded EC values between 0.384 – 1.875 dS/m. Water samples have moderate to high-salinity (if EC values between 0.205 and 2.250 dS/m), yet these can be used for the irrigation of the crops. pH values of water samples are found between 7.18-8.10, meaning that they are slightly alkaline. Bicarbonate concentrations of 19 of the water samples are greater than 200 mg/L. These waters may not be suitable for irrigation of ornamental plants. All of the water samples, except water samples from Gölbaşı, have sodium absorption ratio (SAR) values between 1 and 9. Water samples with low SAR values, except water samples from Gölbaşı, can be used for irrigation of almost all soils with little danger of developing harmful levels of sodium. The Residual Sodium Carbonate (RSC) values of water samples Ankara Gölbaşı and Sincan-1 are greater than 2.50 meq/L and these water samples are not suitable for the irrigation. RSC values of Etimesgut, Sincan-2 and Kazan water samples are positive and lower than the value 2.00 meq /L. All the other water samples have negative RSC values so they are the safe to use for irrigation.

It has been observed that development of practical field analysis techniques for all soil and water quality parameters may be possible with exception of micronutrient determination. For determining soil and water quality parameters in the rural areas there is a need to establish a small laboratory with necessary equipment and apparatus and training one or two farmers. With the experience gained in this study, some of these techniques may be adapted to the rural field applications, so soil and water may be tested by the farmers for better yields.

Key words: Soil quality, water quality, soil nutrients, irrigation water, agriculture

ÖZ

TARIMSAL ÜRETİM İÇİN TOPRAK VE SU ANALİZ TEKNİKLERİ

Maral, Nuh
Yüksek Lisans, Kimya Bölümü
Tez Yöneticisi: Prof. Dr. G. İnci Gökmen

Mayıs 2010, 108 sayfa

Türkiye'deki bazı bilinçsiz çiftçilerin bitkisel üretim için gübre ve tarım ilaçlarını artan miktarda kullanmaları toprak kirliliğine ve tarımsal üretim için toprağın verimsizliğine neden olmaktadır. Fazla ve/veya düşük kaliteli sulama suyu kullanımı da bitkisel üretim sırasında sorunlara yol açmaktadır. Bu nedenle bu çalışmada toprak ve su kalitesi ODTÜ ve Tarım ve Köyişleri Bakanlığına ait Ankara'daki Toprak Gübre ve Su Kaynakları Merkez Araştırma Enstitüsü Laboratuvarlarında basit ve güvenilir teknikler kullanılarak gerçekleştirilmiştir. Toprak ve su örnekleri standart teknikler kullanılarak Ankara, Bolu, Çorum ve Kırıkkale'den toplanmıştır.

Toprak örneklerinin tekstürü toprak test sonucuna göre tınlı ve killi tınlı olarak belirlenmiştir. Toprak örneklerinin toplam tuz oranı % (a/a) 0.033–0.063 arasında değişmektedir. Tuzluluk oranı % 0.15'ten küçük olduğu için bu topraklar az tuzlu topraklardır. Toprak örneklerinin pH'sı 7.86–8.15 arasında değiştiğinden bu topraklar hafif alkali topraklardır. Toprak örneklerinin fosfor derişimleri 4.95–35.45 P_2O_5 kg/da arasında değişmektedir. Bazı toprak örnekleri fosfor içeren gübre kullanımı nedeniyle yüksek seviyede (P_2O_5 12 kg/da'dan çok) fosfor içermektedir. Toprakların potasyum derişimleri 141–286 K_2O kg/da arasında değişmektedir, dolayısıyla bu topraklardaki potasyum içeriği bitkisel üretim için yeterlidir. Toprakların kireç içeriği ise

% (a/a) 1.04–2.67 $CaCO_3$ arasında bulunmuştur. Toprak örnekleri, kireçli olmakla birlikte yüksek düzeyde kireç içermediklerinden tarımsal üretim için uygundur. Toprakların organik madde içeriği % (a/a) 0.83–2.04 arasında bulunmuştur ve organik madde miktarının bitkisel üretim için yeterli değildir.

Yirmi iki su örneğinin elektriksel iletkenlik (EC) değerleri 0.384–1.875 dS/m arasında bulunmuştur. Su örneklerinin EC değerlerine göre orta tuzluluktan yüksek tuzluluğa (EC değerleri 0.205 ile 2.250 arasında ise) kadar sıralandığı söylenebilir. Su örneklerinin tuzluluk oranları çok yüksek bulunmadığından bitkiler için sulama suyu olarak kullanılabilir. Su örneklerinin pH değerleri 7.18–8.10 arasında bulunmuştur, dolayısıyla bu örnekler hafif alkalidir. Ondokuz su örneğinin bikarbonat derişimleri 200 mg/L'den fazla olduğundan süs bitkilerinin sulanmasında kullanılması uygun değildir. Ankara Gölbaşı'ndan getirilen su numuneleri hariç diğer suların sodyum adsorpsiyon oranı (SAO) 1–9 arasında bulunmuştur. Düşük seviyede sodyum içeren bu su örnekleri bütün topraklarda sulama suyu olarak kullanılabilir. Ankara Gölbaşı ve Sincan 1 su örneklerinde Artık Sodyum Karbonat (ASK) değeri 2.50 meq/L'den yüksek olduğu için bu sular sulama suyu olarak uygun değildir. Etimesgut, Sincan–2 ve Kazan su örneklerinde ASK değeri pozitif ve 2.00 meq/L'den küçük, diğer tüm su örneklerinde ise negatiftir, bu nedenle bu sular sulama için güvenlidir.

Pratik tarla analiz tekniklerini mikro besin elementleri dışındaki parametreler için geliştirmek mümkün olabilir. Kırsal alanda toprak ve su kalitesi parametrelerinin tayini içinde gerekli araç ve aletlerle donatılan küçük bir Laboratuvar kurulması ve bir veya iki çiftçinin eğitilmesiyle mümkün olabilir. Bu çalışmada kazanılan deneyimlerle bu tekniklerin bazıları gelecek yıllarda kırsal kesimde çiftçiler tarafından kolaylıkla uygulanabilecek ve verim artışını sağlayacak toprak ve su testlerine dönüştürülebilir.

Anahtar Kelimeler: Toprak kalitesi, su kalitesi, besin maddeleri, sulama suyu, tarım

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to my supervisor Prof. Dr. G. İnci Gökmen and Prof. Dr. Ali Gökmen for their guidance, advice, criticism, encouragements and insight throughout the research.

I would like to express my sincere appreciation to Directors of Soil-Fertilizer and Water Resources Central Research Institute Dr. Bülent Sönmez and Dr. Nesime Cebel, agricultural engineers Mustafa Usul and Aynur Dilsiz, chemical engineer İlhan Küçükyurt, laboratory technicians Turgut Balcı, Kemal Özkul, Aydın Yetim and İsmail Uğurlu for their support and guidance to improve my skills for the soil and water analyses during my study at Soil-Fertilizer and Water Resources Central Research Institute.

I also would like to thank my family for their patience and support in my work.

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ABBREVIATIONS

Artık sodyum karbonat	ASK
Cation exchange capacity	CEC
Decares	da
DeciSiemens	dS
Diamonium phosphate	DAP
Diethylene triamine pentaacetic acid	DTPA
Electrical conductivity	EC
Ethylenediaminetetraacetic acid	EDTA
Exchangeable acidity	EA
Gross Domestic Product	GDP
Hectare	ha
Inductively Coupled Plasma Optical Emission Spectrometer	ICP-OES
Polyethylene terephthalate	PET
Sodium Adsorption Ratio	SAR
Sodyum adsorpsiyon oranı	SAO
Soil organic matter	SOM
Residual sodium carbonate	RSC
Total dissolved salts	TDS
Triple super phosphate	TSP
Ultraviolet-visible	UV-VIS
United States Department of Agriculture	USDA

CHAPTER 1

INTRODUCTION

Turkey is one of the largest countries in Europe with a large population, land and with great opportunities offered in various areas. In Turkey, share of workforce in agriculture sector has decreased from 36 % in 2000 to 24.7 % in 2009 [1]. Although importance of agriculture in Turkey's economy has decreased relatively, it has still great importance in terms of employment opportunities, meeting the domestic food requirements, supplying input to industry and exporting. When Turkish Republic was established, share of agriculture in gross domestic product (GDP) was: 42.8 % in 1923, then it is decreasing; 36.0% in 1970, 25.5% in 1980, 16.8% in 1990, 13.5% in 2000 and 12.6% in 2003. Share of agriculture in GDP in Turkey has decreased to 7.52% in 2007 as a result of the industrialization and development of services sector [2,3].

Turkey is one of the few countries in the world that is self-sufficient in terms of food production. The good soil quality, access to sufficient water, a suitable climate, and hard-working farmers, all make for a successful agricultural sector. In addition, a broad range of crops can be raised because of the variety of different climates throughout the land. Organic farming and organic products are getting more and more popular in Turkey in parallel with the growing importance and popularity of organic products in Europe [4].

In addition to this, Turkey has a great advantage in the sense that there are still suitable lands for agriculture in Turkey without any pollution which is perfect for organic production. In connection with the trend of consuming healthy products, the popularity and domestic consumption of poultry products are increasing which means that there is great potential in business opportunities within areas such as machinery, animal feeds and vitamins, consultancy services, etc [4].

Irrigation is a means of reducing weather-induced production variations. Therefore, Turkey is giving high priority to improve land and water resources and expanding irrigation. It has designated about two-thirds of total public agricultural investment for land and water improvement by analyzing soil and irrigation water [5].

An important factor influencing the productivity of our planet's various ecosystems is the nature of their soils. Soils are vital for the existence of many forms of life that have evolved on our planet [6]. Soil is a natural body comprised of solids, liquids, and gases that occurs on the land surface, occupies space, and is characterized by one or both of following: horizons or layers that are distinguishable from the initial material as a result of additions, losses, transfers and transformations of energy and matter, or the ability to support rooted plants in a natural environment [7].

Soils tend to have distinct variations in color both horizontally and vertically (Figure 1.1). The coloring of soils occurs because of a variety of factors. Soils of the humid tropics are generally red or yellow because of the oxidation of iron or aluminum, respectively. In the temperate grasslands, large additions of humus cause soils to be black. The heavy leaching of iron causes coniferous forest soils to be gray. High water tables in soils cause the reduction of iron, and these soils tend to have greenish and gray-blue hues. Organic matter colors the soil black [6].

The combination of iron oxides and organic content gives many soil types a brown color. Other coloring materials sometimes present include white calcium carbonate, black manganese oxides, and black carbon compounds [6].

Figure 1.1. The colors of soil types [8]

Variety of techniques are used to determine the efficiency of land, these techniques are listed as follows:

- Soil texture analysis,
- Biological testing of some microorganisms,
- Chemical soil analysis.

Soil analyses are performed for the soil fertility and plant nutrition. Soil analyses as well as fertilizers or nutrients are very important in terms of detection of needs for organic and inorganic nutrients by the poor soil.

In Turkey, Ministry of Agriculture and Rural Affairs founded Soil and Water Resources Research Institutes in Şanlıurfa, Konya, Kırklareli, Mersin, İzmir, Erzurum, Samsun, Eskişehir, Tokat and Ankara for the soil and water quality determinations.

Ankara Soil Fertilizer and Water Resources Central Research Institute is best known center of the Turkey for the soil, fertilizer and water analysis. Some of the important projects for agriculture in Turkey have been examined in this institute. This institute makes recommendations, produce and implement the policies for the soil, fertilizer and water issues by applying international standards on research. In this study some of measurements and experiments for the soil and water quality were carried out in this institute.

There are 16 nutrient elements which are known to be required for plant growth (Table 1.1). Essential nutrients carbon, hydrogen and oxygen are taken up from atmospheric carbon dioxide and water. The other nutrients are taken up from the soil and are usually grouped as primary nutrients, secondary nutrients and micronutrients [9].

- The primary nutrients: nitrogen, phosphorus, and potassium are commonly found in blended fertilizers such as in ratio of 10-10-10 (10 % N, 10 % P_2O_5 and 10 % K_2O) or equivalent grades. Primary nutrients are utilized in the largest amounts by crops, and therefore, are applied at higher rates than secondary nutrients and micronutrients.

- The secondary nutrients: calcium, magnesium and sulfur are required in smaller amounts than the primary nutrients. The major source for supplementing the soil with calcium and magnesium is dolomitic lime which is the natural limestone that contains calcium oxide and magnesium oxide, although these nutrients are also available from a variety of fertilizer sources. Sulfur is available in fertilizers such as potassium and magnesium sulfate, gypsum (calcium sulfate), and elemental sulfur.

- Micronutrients: boron, chlorine, copper, iron, manganese, molybdenum and zinc are required in even smaller amounts than secondary nutrients.

They are available in manganese, zinc and copper sulfates, oxides, oxy-sulfates and chelates, as well as in boric acid and ammonium molybdate.

Table 1.1. Nutrients essential for plant growth [9]

Nutrients from Air and Water	**Nutrients From Soil, Lime and Commercial Fertilizers**		
	Primary Macronutrients	**Secondary Macronutrients**	**Micronutrients**
Carbon	Nitrogen	Calcium	Boron
Hydrogen	Phosphorus	Magnesium	Chlorine
Oxygen	Potassium	Sulfur	Copper
			Iron
			Manganese
			Molybdenum
			Zinc

Three major factors contributing to plant nutrition are:

1. The amount of nutrients in the soil,
2. The soil's ability to supply the nutrients to plants,
3. Environmental factors that affect nutrient availability and their absorption.

Parameters used for the efficiency analyses in soil are shown in Table 1.2.

Table.1.2. Parameters used for efficiency analyses in soils [10]

Nutrients	**Very low**	**Low**	**Medium**	**High**	**Too High**
% (w/w) N	<0.045	0.045-0.09	0.10-0.17	0.18-0.32	>0.32
P mg kg^{-1}	<2.5	2.5-8.0	8.1-25	26-80	>80
K mmoles 100g^{-1}	<0.13	0.13-0.28	0.29-0.74	0.75-2.56	>2.56
Ca mmoles 100g^{-1}	<1.19	1.19-5.75	5.75–17.5	17.5–50.0	>50.0
Mg mmoles 100g^{-1}	<0.42	0.42-1.33	1.34-4.0	4.1–12.5	>12.5
Mn mg kg^{-1}	<4	4-14	15-50	51-170	>170
Zn, mg kg^{-1}	<0.2	0.2-0.7	0.8-2.4	2.5-8.0	>8.0
B mg kg^{-1}	<0.4	0.4-0.9	1.0-2.4	2.5-4.9	>5
	Low	**Marginal**	**Adequate**		
Fe mg kg^{-1}	<2.5	2.5-4.5	>4.5		
	Deficient	**Efficient**			
Cu mg kg^{-1}	<0.2	>0.2			
	Slightly Calcareous	**Calcareous**	**Moderately Calcareous**	**Strongly Calcar.**	**Extrem. Calcar.**
% (w/w) Lime	0.0-1.0	1.1-5.0	5.1-15	15.1-25.0	>25
	Not salty	**Slightly salty**	**Moderately salty**	**Strongly salty**	
% (w/w) Salt	0-0.15	0.16-0.35	0.36-0.65	>0.65	
	Too low	**Low**	**Medium**	**Good**	**High**
% (w/w) Organic Matter	0.0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	>4
Strongly acidic	**Moderately acidic**	**Slightly acidic**	**Neutral**	**Slightly Alkaline**	**Strongly Alkaline**
pH <4.5	4.5-5.5	5.6-6.5	6.6-7.5	7.6-8.5	>8.5
Texture	**Sand**	**Loam**	**Clay Loam**	**Clay**	**Heavy clay**
% saturation	0-30	31-50	51-70	71-110	>110

Soil analyses are very important to get high quality products and to prevent more fertilizer usage in the soil. Soil analyses are made to understand the texture of soil and find concentration of nutrition elements. Generally pH, EC (electrical conductivity), nitrogen, phosphorus, potassium, lime, micro elements and organic matter determinations in soil are known as Soil Fertility Analyses.

1.1. SOIL QUALITY

1.1.1. Saturation Percentage and Soil Texture

Soil texture is a term commonly used to designate the proportionate distribution of the different sizes of mineral particles in a soil. It does not include any organic matter. These mineral particles vary in size from those easily seen with the unaided eye to those below the range of a high-powered microscope. According to their size, these mineral particles are grouped into "separates". A soil separate is a group of mineral particles that fit within definite size limits expressed as diameter in millimeters. Sizes of the separates used in the United States Department of Agriculture (USDA) system of nomenclature for soil texture are shown in Figure 1.2 [11].

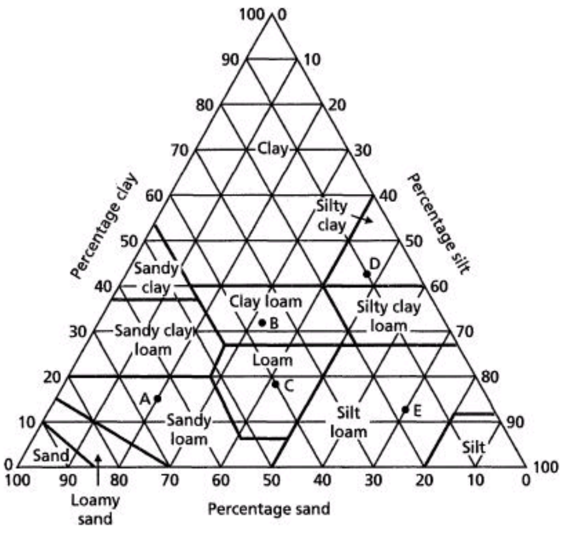

Figure 1.2. Nomenclature for soil texture

Soil texture is determined by the relative proportion of sand, silt and clay found in a given soil. The term "texture" refers to the size of the individual soil particles and has nothing to do with the amount of organic matter present in the soil [12].

- Sand is gritty to the touch and the individual grains or particles can be seen with the naked eye. It is the largest of the three size classes of soil particles. A soil in which sand predominates is classified, logically enough, as a sand-textured soil or simply a sandy soil.

- Silt is smooth and slippery to the touch when wet and the individual particles are much smaller than those of sand. These individual particles can only be seen with the aid of a microscope. Silt-textured or silt soils contain relatively large amounts of silt.

- Clay is sticky and plastic-like to handle when wet. The individual particles are extremely small and can only be seen with the aid of an electron microscope. Clay-textured, or clay soils, are rich in clay and fine in texture [12].

In US the soil texture is classified based on the United States Department of Agriculture (USDA) system. The classification of particle sizes are the following (units in mm) [13]:

- clay: < 0.002
- silt: 0.002 – 0.05
- fine sand: 0.05 – 0.1
- medium sand: 0.1 – 0.5
- coarse sand: 0.5 – 1.0
- very coarse sand: 1.0 – 2.0
- gravel: 2.0 – 762.0
- cobbles: > 762.0

Importance of Soil Texture [14]

A clay soil is referred to as a fine-textured soil whereas a sandy soil is a coarse textured soil. Numerous soil properties are influenced by texture including:

- Drainage
- Water holding capacity
- Aeration
- Susceptibility to erosion
- Organic matter content
- Cation exchange capacity (CEC)
- pH buffering capacity
- Soil tilth (the act or work of tilling- plowing land)

Many analytical laboratories determine the soil saturation percentage (such as the amount of water, by weight, in a saturated soil sample) and make indirect soil texture determinations, as it is given in Table 1.3 [15].

The saturation percentage is directly related to the total soil porosity and total soil water-holding capacity and, therefore, is a valuable number to use for irrigation system design [16].

Table 1.3. Saturation percentage and texture

Texture	Sand	Loam	Clay Loam	Clay	Heavy clay
% saturation	0-30	31-50	51-70	71-110	>110

Texture is an important soil characteristic because it will, in part, determine water intake rates as known infiltration; water movement through soil (hydraulic conductivity); soil water holding capacity; the ease of tilling the soil; and the amount of aeration which is vital to root growth. Texture will also influence soil fertility [16].

1.1.2. Soil pH

The pH is a measure of the acidity in the soil solution as shown in Figure 1.3. In addition, soil pH is one of the most important and common measurements performed in standard soil analyses. Most soil chemical and biological reactions are controlled by the pH of the soil solution in equilibrium with soil particle surfaces [17].

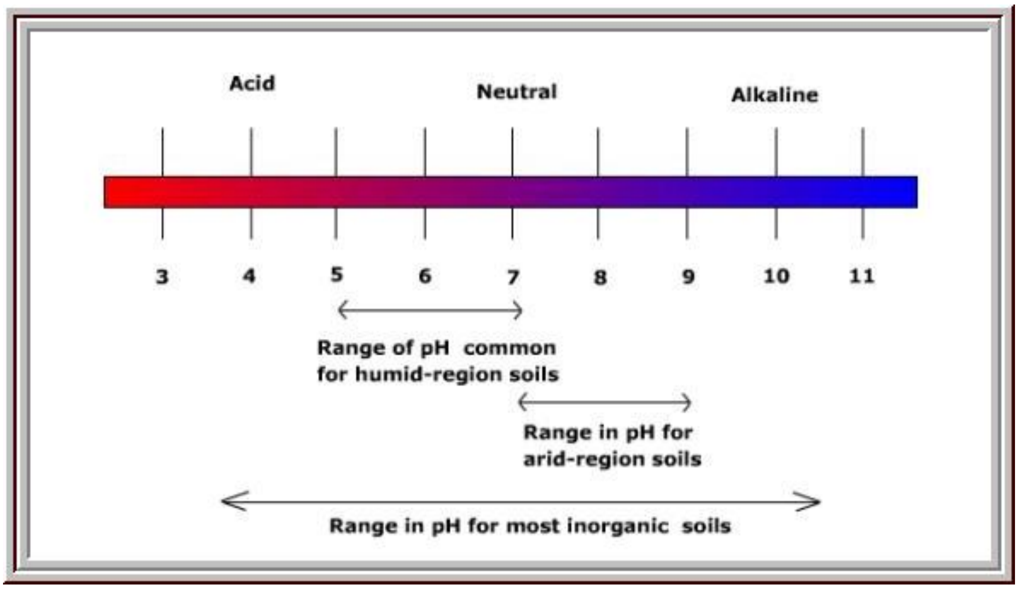

Figure 1.3. Range of soil pH [18]

The desirable pH range for optimum plant growth varies among crops. Some of the crops are grown in the pH 6.0 to 7.0. On the other hand others are grown well in slightly acidic conditions [18].

The pH of soil or more precisely the pH of the soil solution is very important because soil solution carries in it nutrients such as nitrogen, potassium, and phosphorus that plants need in specific amounts to grow, thrive, and fight off diseases. If the pH of the soil solution is increased above 5.5, nitrogen (in the form of nitrate) is made available to plants. Phosphorus, on the other hand, is available to plants when soil pH is between 6.0 and 7.0 [19].

If the soil solution is too acidic, plants cannot utilize N, P, K and other nutrients. The development of strongly acidic soils (pH less than 4.5) can result in poor plant growth as a result of one or more of the following factors: aluminum toxicity, manganese toxicity, calcium deficiency, magnesium deficiency, and low levels of essential plant nutrients such as phosphorus and molybdenum [20].

Soils become acidic when basic elements, such as calcium, magnesium, sodium, and potassium held by soil colloids are replaced by hydrogen ions. Rainfall contributes to soil acidity because water combines with carbon dioxide to form a weak acid, H_2CO_3. When the weak acid ionizes, it releases hydrogen (H^+) and bicarbonate ion (HCO_3^-). The released hydrogen ions replace the calcium ions held by soil colloids, causing the soil to become acidic. The displaced Ca^{2+} ions combine with the bicarbonate ions to form calcium bicarbonate, which, being soluble, is leached from the soil. The net effect is increase in soil acidity [18].

Nitrogen fertilizers and many plants also contribute to the soil acidity. Because nitrogen sources (fertilizers, manures, legumes) contain or form ammonium ion that increase soil acidity unless the plant directly absorbs the ammonium ions. Greater the nitrogen fertilization rates with these sources, greater may be the soil acidification. Ammonium is converted to nitrate in the soil (nitrification) and H^+ ions are released. For each 1.0 kg of nitrogen as ammonium or forming ammonium in urea, ammonium nitrate, and anhydrous ammonia, it takes approximately 1.8 kg of pure calcium carbonate to neutralize the residual acidity. The nitrate that is provided or that forms can combine with basic cations like calcium, magnesium, and potassium and leach from the topsoil into the subsoil. As these bases are removed and replaced by H^+ ions, soils become more acidic [18].

To decrease soil acidity (raise the pH), the soil is usually amended with alkaline materials that provide conjugate bases of weak acids (carbonate and hydroxide). These conjugate bases are anions that are capable reacting with H^+ ions to form weak acids (such as water). For example:

$$CO_3^{2-} + 2\,H^+ \rightarrow CO_2 + H_2O$$

These bases are supplied in their calcium and magnesium forms ($CaCO_3$, etc.) and are referred to as agricultural limes. Some liming materials contain CaO and MgO, which forms hydroxide ions in water. Liming materials are used to supply plant nutrients in relatively small amounts for plant nutrition [21].

The pH value alone does not determine how much lime is required but is used in conjunction with exchangeable acidity (EA) in determining lime rates. The pH determination is useful for indicating when too much lime has been applied and for evaluating micronutrient availability, particularly manganese [22].

1.1.3. Soil Electrical Conductivity (EC)

Ions in aqueous solution conduct electricity, therefore the total amount of soluble soil ions can be determined by measuring the soil EC of a soil water extract. Soil EC is the measure of how much electrical current soil can conduct. The unit of EC is deciSiemens per meter (dS/m). Generally EC measurements are used for the determination of soil salinity. Soils can be classified by the EC measurements related with amount of soluble salts and sodium adsorption ratio (SAR).

Soil EC is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics. EC measurement shows [23]:

- How soil EC can be related to specific soil properties that affect crop yield, such as top soil depth, pH, salt concentrations, and available water-holding capacity

- Soil EC maps often visually correspond to patterns on yield maps and can help explain yield variation

Classifications of soil salinity are shown in Table 1.4 with respect to electrical conductivity soil water suspension [24].

Table 1.4. Soil salinity classification

Soil Texture	**Degree of Salinity (Electrical Conductivity) dS/m**				
	None	**Slight**	**Moderate**	**Strong**	**Very Strong**
Course sand to sandy loam	‹ 1.2	1.2-2.4	2.5-4.4	4.5-8.9	› 9.0
Loamy fine sand to loam	‹ 1.3	1.3-2.4	2.5-4.7	4.8-9.4	› 9.5
Silt loam to clay loam	‹ 1.4	1.4-2.5	2.6-5.0	5.1-10.0	› 10.1
Silty clay loam to clay	‹ 1.5	1.5-2.8	2.9-5.7	5.8-11.4	› 11.5

The conduction of electricity in soils takes place through the moisture-filled pores that occur between soil particles. Therefore, the EC of soil is influenced by the interactions between the following soil properties [25]:

- **Pore Continuity:** Soils with water-filled pore spaces that are connected directly with neighboring soil pores tend to conduct electricity more readily. Soils with high clay content have numerous, small water-filled pores that are quite continuous and usually conduct electricity better than sandier soils. Compaction normally increases the soil EC.

- **Water content:** Dry soils are much lower in conductivity than moist soils.

- **Salinity level:** An increasing concentration of electrolytes (salts) in soil water will dramatically increase soil EC. The salinity level in most humid regions is normally very low. However, there are areas that are affected by Ca^{2+}, Mg^{2+} or other salts that will have elevated EC levels.

- **Cation exchange capacity (CEC)**: Mineral soils containing high levels of organic matter (humus) and/or 2:1 clay minerals such as montmorillonite, illite or vermiculite have a much higher ability to retain positively charged ions (such as Ca^{+2}, Mg^{+2}, K^+, Na^+, NH_4^+, or H^+) than soils lacking these constituents. The presence of these ions in the moisture-filled soil pores will enhance soil EC in the same way that salinity does.

- **Depth:** The signal strength of EC measurements decreases with soil depth. Therefore, subsurface features will not be expressed as intensely by EC mapping as the same feature if it were located nearer to the soil surface.

- **Temperature:** As temperature decreases toward the freezing point of water, soil EC decreases slightly. Below freezing, soil pores become increasingly insulated from each other and overall soil EC declines rapidly.

1.1.4. Lime in Soil

Lime is the term used for crushed limestone. Limestone is mined as rock and is crushed mechanically to varying degrees of fineness. In most cases, lime is comprised primarily of calcium carbonate, also called calcite. Some limestone may contain relatively high (5 % to 12 %) contents of $MgCO_3$ as well as $CaCO_3$. These materials are called dolomites. Dolomite should only be used in situations where soil analysis has shown a definite need for magnesium [26].

The lime content of soil is an important factor in agriculture because it has a significant bearing on physical and chemical properties of soils as well as on growth and production of crops. In addition, the distribution of lime content in soil profiles tells a story of soil genesis and has been used as criteria for soil classification [27].

The important consideration is lime placement added to soil. Ground agricultural limestone is relatively insoluble in water so maximum contact with the soil is necessary to neutralize the soil acidity. Lime will not move into the soil like water soluble fertilizers.

Lime reduces soil acidity (increases pH) by changing some of the hydrogen ions into water. Ca^{2+} ion from the lime replaces two H^+ ions on the cation exchange complex as is shown Figure 1.4. The carbonate (CO_3^-) reacts with water to form bicarbonate ion. These react with H^+ to form H_2O and CO_2. The pH increases because the H^+ concentration has been reduced [26].

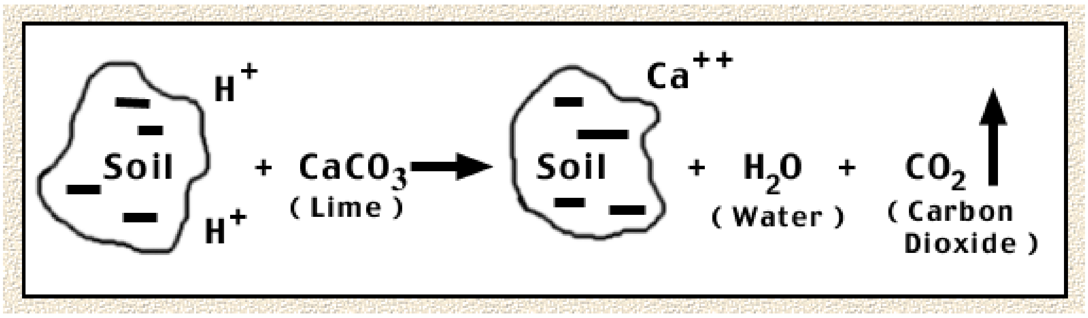

Figure 1.4. Lime reaction

Soil of low rainfall areas commonly accumulates calcium carbonate that forms a calcic horizon at some depth in the soil profile. Calcareous soil materials can be distinguished in the field by the effervescence that occurs if a drop of acid is applied. The high carbonate concentration in these horizons can inhibit root growth for some plants [21].

In regions of very low rainfall, carbonate concentration may be found at or near the soil surface. In these cases, serious micronutrients and phosphorus deficiencies can be induced in plants that are adapted to calcareous conditions. In other words in alkaline soils, one or some subsoil layers may be cemented into hard, concrete like horizons such as petrocalcic layers [21].

1.1.5. Soil Organic Matter

Soil organic matter (SOM) is a complex and varied mixture of organic substances. All organic substances, by definition, contain the element carbon, and, on the average, carbon comprises about half of the mass of soil organic matter [21].

Soil organic matter is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process. At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (Figure 1.5). Most soil organic matter originates from plant tissue. Plant residues contain 60–90 % moisture. The remaining dry matter consists of carbon, oxygen, hydrogen and small amounts of sulfur, nitrogen, phosphorus, potassium, calcium and magnesium. Although present in small amounts, these nutrients are very important from the view point of soil fertility management. The transformation and movement of materials within soil organic matter pools is a dynamic process influenced by climate, soil type, and vegetation and soil organisms. The benefits of a soil that is rich in organic matter and hence rich in living organisms are many [28].

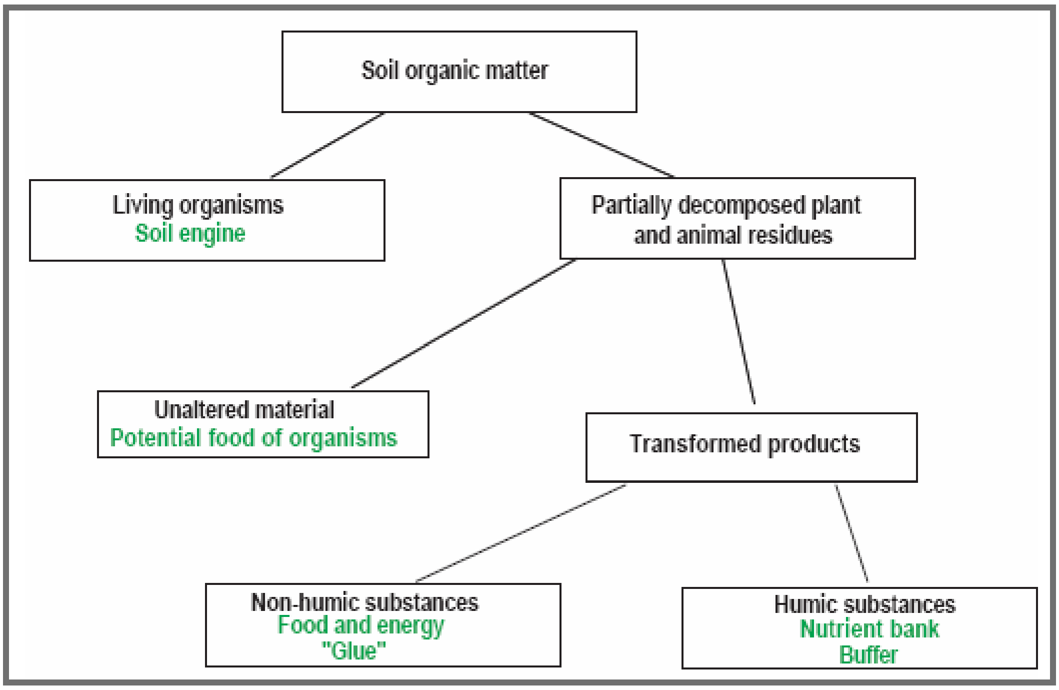

Figure 1.5. Soil organic matter constituents [28]

Knowledge of soil organic matter content is important in herbicide applications, pH maintenance, and general soil quality and productivity assessments [29-31].

1.1.6. Soil Phosphorus

Phosphorous is a nonmetal element of the V-A group in periodic table. There are several allotropic forms of phosphorous in nature. The two most common allotropes are white and red phosphorous. It is an essential element for the life of organisms and soil. Phosphorous is never found in pure form in the nature, but only as phosphates, which consists of a phosphorous atom bonded to four oxygen atoms in the phosphate ion and oxides. Phosphorus is an essential element for plant growth and is often applied to agricultural land to increase crop production. Animal waste generally has a high concentration of phosphorus. Livestock feedlots and cattle grazing on grassland can introduce substantial amounts of phosphorus rich manure to the environment [32].

Phosphorus is lost from agricultural land to surface water bodies in sediment-bound and dissolved forms. Sediment-bound P includes P associated with minerals and organic matter. Dissolved P constitutes 10 to 40 % of the P transported from most cultivated soils to water bodies through runoff and seepage [33].

Surface runoff from grassland, forest, and uncultivated soils carries little sediment and carries dominantly dissolved forms of P. Unlike sediment-bound P, dissolved P is readily bioavailable and thus is the main cause of eutrophication. A concentration of P above 0.02 mg/L in lake water generally accelerates eutrophication. This concentration is much less than the P concentration in soil solution of cultivated soils and leads us to an important question regarding the relationship between P in soil and surface runoff. Selection of an appropriate soil test is essential for understanding this relationship and for identifying nonpoint sources of P contamination from agricultural land [34].

1.1.7. Soil Potassium

Many plant physiologists consider potassium second only to nitrogen in importance for plant growth. Potassium is second to nitrogen in plant tissue levels with ranges of 1 to 3% by weight. Potassium is an essential nutrient in the plants tolerance to stresses such as cold and hot temperatures, drought, and wear and pest problems. Potassium acts as catalysts for many of the enzymatic processes in the plant that are necessary for plant growth to take place. Another key role of potassium is the regulation of water use in the plant (osmoregulation). This osmoregulation process affects water transport in the xylem (in vascular plants, xylem is one of the two types of transport tissue), maintains high daily cell turgor pressure which affects wear tolerance, affects cell elongation for growth and most importantly it regulates the opening and closing of the stomates which affect transpiration cooling and carbon dioxide uptake for photosynthesis [35].

The potassium in soil is found in three forms, unavailable, slowly available and exchangeable. Unavailable potassium is contained within the crystalline structure of micas, feldspars and clay minerals. Plants can not use this form of potassium. Over long periods, these minerals break down, release their potassium as the available K^+ ion as is shown Figure 1.6 [36]

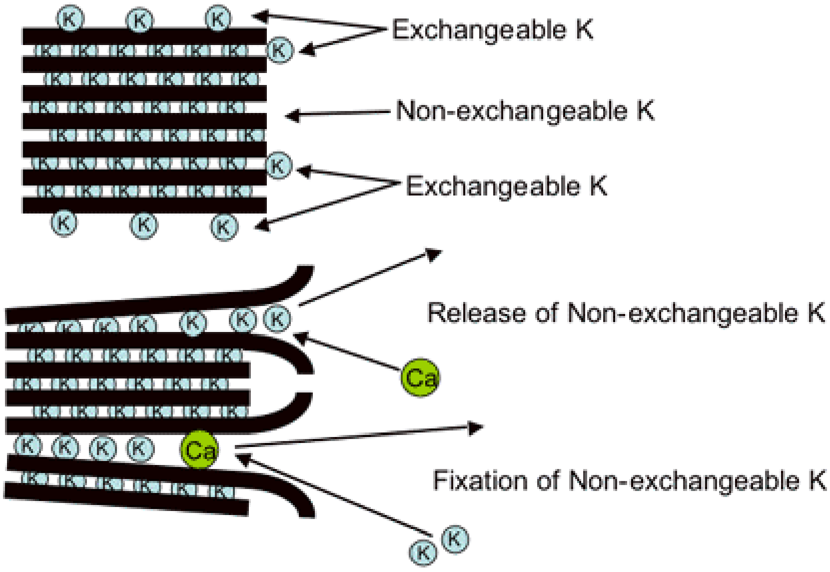

Figure 1.6. Exchangeable and non-exchangeable potassium [37]

Slowly available (fixed) potassium is trapped between the layers of plate of certain kinds of clay minerals. Plants can not use much of fixed potassium during a single growing season. However, the supply of the fixed potassium largely determines soil's ability to supply potassium over extended period of time. Exchangeable potassium is dissolved in soil water or held on the surface of clay particles. Dissolved potassium level in the soil water is usually around 5-10 mg/L. Plants absorb this form of potassium readily, and as soon as the concentration of potassium in the soil solution drops, more is released into solution from the exchangeable form. Most of soil tests for determination of potassium measure the readily available forms but not the slowly available and unavailable forms [36].

Potassium uptake by plants is affected by several factors [38]:

- **Soil Moisture:** Higher soil moisture usually means greater availability of K^+. Increasing soil moisture increases movement of K^+ to plant roots and enhances availability. Generally, in dry years higher responses to K^+ fertilization is observed.
- **Soil Aeration and Oxygen Level:** Air is necessary for root respiration and K^+ uptake. Root activity and subsequent K^+ uptake decrease as soil moisture content increases to saturation. Levels of oxygen are very low in saturated soils.
- **Soil Temperature:** Root activity, plant functions, and physiological processes all increase as soil temperature increases. This increase in physiological activity leads to increased K^+ uptake. Optimum soil temperature for uptake is 16-27 °C. Potassium uptake is reduced at low soil temperatures.
- **Tillage System**: Tillage is the agricultural preparation of the soil by ploughing, ripping, or turning it. Availability of soil K^+ is reduced in no-till and ridge-till planting systems. The exact cause of this reduction is not known. Results of research point to restrictions in root growth combined with a restricted distribution of roots in the soil.

1.1.8. Soil Nitrogen

Nitrogen is also an essential plant nutrient. Nitrogen is found primarily in organic forms in soil, move in soil and plants mostly in the anionic form. At the same time is responsible for serious environmental problems. Excesses of some nitrogen compounds in soils can adversely affect human and animal health. High nitrate concentration in soil can lead to sufficiently high nitrates in drinking water as to endanger to the health of human infants and some animals [39].

Nitrogen is present in soils in organic and inorganic forms. There is a wide variation in the types of organic compounds that contain nitrogen. Organic compounds can be small and easily degraded by microorganisms like amino acids, or large complex molecules that are quite resistant to microbial decay. The most resistant of these soil organic materials are typically referred to as humus. Inorganic forms of nitrogen are nitrate, nitrite, ammonium, and ammonia. Nitrate and ammonium are readily taken up by plants and beneficial for plant growth. Nitrite and ammonia are toxic to plants [40].

Living plants cannot use organic forms of N. This is why microbes living in the soil are so valuable, because they can convert organic N into inorganic forms of N that plants can then use. Temperature, moisture, fertilization and cropping, factors influence its dynamic relationship with the organic fractions, and also within the inorganic forms. Nitrogen is an integral component of many essential plant compounds. It is basic molecule of amino acids of proteins and enzymes which control virtually all biological processes. Other essential nitrogenous plant components include the nucleic acids, in which heredity control is vested and chlorophyll, which is at the heart of photosynthesis. A good supply of nitrogen stimulates root growth and development [39].

Plants absorb nitrogen from the soil as both NH_4^+ and NO_3^- ions, but because nitrification is so pervasive in agricultural soils, most of the nitrogen is taken up as NO_3^-. NO_3^- moves freely toward plant roots as they absorb water. Once inside the plant NO_3^- is reduced to an NH_2 form and is assimilated to produce more complex compounds. Because plants require very large quantities of nitrogen, an extensive root system is essential to allow unrestricted uptake. Plants with roots restricted by compaction may show signs of nitrogen deficiency even when adequate nitrogen is present in the soil. Most plants take nitrogen from the soil continuously throughout their lives and nitrogen demand usually increases as plant size increases [41].

1.1.9. Soil Sulfur

Sulfur is a major macronutrient for plants. For many years, the significance of sulfur was neglected, because there were no serious problems in S nutrition of crops, due to the liberal use of ammonium sulfate, super-phosphate (%18 (P_2O_5), and potassium sulfate fertilizers. However, today the importance of S is recognized for improving yields of plants, containing significant amounts of essential amino acids, proteins and vitamins [42]. In addition to its vital roles in plant and animal nutrition, sulfur is also responsible for several types of air, water, and soil pollution and is therefore of increasing environmental interest. The environmental problems associated with sulfur include acid precipitation, certain types of forest decline, acid mine drainage, acid sulfate soils, and even some toxic effects in drinking water used by humans and livestock [21].

It is present in soils in organic and inorganic forms. 90% of the S in plants is present in the form of amino acids. In active volcanic regions, volcanic gas and eruptions are adding substantial amounts of inorganic sulfur in elemental form to the soils [42].

The total S content in soils varies widely from soil to soil. Sandy soils in the humid regions are generally low in S (0.002% w/w). In contrast, soils in arid regions may contain 5% (w/w) S. In general, the total S content in agricultural soils of humid and semi humid regions ranges from 0.01 to 0.05% (w/w), which is equivalent to 224-1120 kg Sulfur /ha. Fertilizers, such as ammonium sulfate, super-phosphate, and potassium sulfate, are well known for bringing significant amounts of S in soils [42].

1.1.10. Micronutrients in Soil

The nine so- called micronutrients or trace elements are no less important to plant growth than are the macronutrients; they are merely needed in much smaller quantities. These are iron, manganese, zinc, copper, cobalt, nickel, boron, molybdenum and chlorine [39].

Micronutrients play many complex roles in plant nutrition, but most of them are used in the functioning of a number of enzyme systems. However, there is considerable variation in the specific functions of the various micronutrients in plants and in microbial growth processes. The functions of soil micronutrients for crops are listed in Table 1.5 [39].

Table 1.5. Soil micronutrients

Elements	Functions
Iron	• Present in several important enzymes • Important in chlorophyll formation
Manganese	• Activates a number of important enzymes • Important in photosynthesis and nitrogen metabolism
Zinc	• Promotes the formation of growth hormones and starch • Present in a number of enzymes • Promotes seed development
Copper	• Present in several enzymes • Important in photosynthesis, protein and carbohydrate metabolism, and probably nitrogen fixation
Boron	• Activates certain dehydrogenize enzymes • Facilitates translocation of sugar in the plant, and the synthesis of nucleic acids and plant hormones • Essential for cell division and development
Molybdenum	• Present in various enzymes • Essential for nitrogen fixation and nitrogen assimilation
Chlorine	• Plays a role in photosynthesis and enzyme activation • Regulates the opening of the leaf stomata

Microelements are necessary in very small quantities, their concentrations in plant tissue being one or more orders of magnitude lower than the macronutrients. Sources of the seven micronutrients vary markedly from one area to another. The content of these elements in soils and in crops are shown in Table 1.6 [39].

Table 1.6. Some important micronutrients and content of these nutrients in soils and, in harvested crops

Element	Levels usually found in		Crop/soil ratio
	Soils kg/ha	Crops mg/kg	
Fe	56000	2	1: 28000
Mn	2200	0.5	1: 4400
Zn	110	0.3	1: 366
Cu	45	0.1	1: 450
B	22	0.2	1: 110
Mo	5	0.02	1: 250
Cl	22	2.50	1: 0.9

- **Iron** [43] is involved in the production of chlorophyll. Iron is also a component of many enzymes associated with energy transfer, nitrogen reduction and fixation, and lignin formation. Iron serves a direct role in gathering and moving charged electrons, and is directly responsible for the production of respiration energy. Cytochromes are a group of iron-keyed enzymes which function as intermediate carriers of electron energy in oxidation processes in the plant.

  Iron is most soluble in the lowest pH ranges suitable for plant growth. Increasing pH favors both chemical and microbial oxidation of this element, and its ionic activity drops as with manganese. Above pH 6.5, insoluble iron oxides predominate. The uptake of iron has also been shown that phosphates will inhibit iron uptake by plants, perhaps by forming some insoluble complex.

  Iron deficiency is seen in calcareous and alkaline soils with soil pH above 7.5. Iron deficiencies are mainly manifested by yellow leaves due to low levels of chlorophyll.

- **Manganese** acts as an enzyme activator for nitrogen assimilation. It is essential for the manufacture of chlorophyll. Low plant manganese, therefore, reduces the plant chlorophyll content causing leaves to turn yellow. Organic soils usually have low to intermediate amounts of manganese. Due to the acidic nature of organic soils, manganese deficiency is rarely observed even when soil manganese is less than 4 mg/L [9].

- **Zinc,** like manganese, is most available at about pH 5.0. Zinc also may react to form insoluble carbonates and slightly soluble hydroxide complexes. The availability of the zinc is not directly pH dependent as is manganese since its state of oxidation does not change over the pH range where plants normally grow. Colloidal organic matter, like clay, absorbs zinc. In plant roots, phosphorus may tie up some zinc [43].

  Zinc is the micronutrient key that activates the enzyme system responsible for the production of auxin when properly combined in the plant, becomes a growth regulator. This chemical agent, active in very small amounts, is carried to the growing points of the plant where it directs the growth effects. Such a chemical agent is known as a "growth hormone". Because of its relationship to the production of the growth regulator, a deficiency of zinc is characterized by a lack of growth in terminal locations where these regulators should be active. When adequate zinc is applied as a soil amendment or as a foliar spray, the immediate result is an increase in auxin and a correction of the stunning effect first noted [43].

- **Copper** is an essential nutrient needed for the normal growth, development of cereal crops. Chlorophyll production, protein synthesis and respiration are important plant functions that need copper. About 70 % of the copper in plants is found in the chlorophyll [44,45].

A copper deficiency can result in early aging or lowered levels of chlorophyll, which leads to yield reductions that go unnoticed if the deficiency is not severe. Copper is removed in the grain of cereal crops at the rate of 5.60 kg/km^2.yr compared to1120 to 11200 kg/km^2.yr for major nutrients such as nitrogen, phosphate, potash and sulfur. If straw is taken from a field an additional 2.24 kg/km^2 to 4.48 kg/km^2 of copper may be removed. Copper deficient soils have several characteristics related to texture, organic matter and soil pH that indicate where a deficiency will likely occur [44,45].

- **Texture**: Deep sandy and light loamy easily worked soils are more prone to copper deficiency than medium and heavy textured clay-type soils.
- **Organic matter:** Copper is strongly bound to organic matter. Peat soils and mineral soils with high levels of organic matter (6-10 %) are most likely to be deficient in plant available copper. Livestock manure and residues from the previous crop also influences soil copper availability.
- **Soil pH:** Copper availability is reduced as pH increases to 7 and above. However, the pH of copper deficient mineral soils ranges from 5.8 to 6.8.
- **Other soil nutrients:** High nitrogen levels delay the translocation of copper from older leaves to the growing points (i.e., head development), significantly enhancing copper deficiency. High levels of phosphorous, zinc, iron, manganese and aluminum may also restrict copper absorption by cereal roots.

- **Boron (B)** is an enzyme activator and is involved in the production of starch required for production of cellulose. The major function of boron is in sugar transport to meristem regions of roots and tops. This is evidenced by the fact that transport of sugars is retarded in boron-deficient plants, resulting in reduced growth.

Boron is also thought to be involved in cell formation and development; nitrogen metabolism; flower fertilization; active salt absorption; hormone, fat, and phosphorus metabolism; and photosynthesis. However, the general consensus is that all of these metabolic processes benefit directly from the influence of boron in sugar transport throughout the plant [9].

Boron is most available above pH 5.0. Below pH 5.0 the boron forms insoluble borosilicate containing iron and aluminum. On the alkaline side, the relative insolubility of calcium borate accounts for the decrease in boron availability. Above pH 8.5 the soil solution is dominated by sodium, which forms a more soluble borate product [43].

- **Molybdenum (Mo)** is required for symbiotic nitrogen fixation (nodulation) by legumes and reduction of nitrates for protein synthesis. Plants require molybdenum levels of 0.1 to 2.5 mg/L in their tissues for normal growth. Recommended soil application rates for molybdenum fertilizer, however, range only from 11.2 to 56.0 kg Mo/ km^2. Applying higher rates can create problems [9].

  High molybdenum content in forage crops can also interfere with copper uptake in ruminant animals ultimately causing a copper deficiency. Therefore, caution is needed when applying molybdenum to crops scheduled for grazing or silage. Its availability increases with soil pH, meaning deficiency symptoms occur most frequently under acid soil conditions. Molybdenum availability varies with soil type, being highest on organic soils, less on clays, and least of all on sandy-textured soils [9].

- **Chlorine (Cl)** is absorbed in larger quantities by most crop plants than any of the micronutrients except iron. Most of the chlorine in soils is found in the form of chloride ion, which leaches rather freely from humid-region soils [39].

Most of chloride functions are related to salt effects (stomatal opening) and electrical charge balance. Chloride in soil also indirectly affects plant growth by stomatal regulation of water loss.

1.1. IRRIGATION WATER QUALITY

Water is an important resource for every type of cultivation. It must not only be available but must also be of sufficient quality [46]. Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use that is how well the quality meets the needs of the user. Quality is defined by certain physical, chemical and biological characteristics. Even a personal preference such as taste is a simple evaluation of acceptability. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water [47].

One can use rainwater, well water, surface water (pond or river) or town or city water. Water quality plays a crucial role in successful production of ornamental crops, determining which crops can be grown and how irrigation and fertilization must be managed. A thorough water analysis and evaluation is therefore important for any ornamental plant production operation. Many plants respond satisfactorily to irrigation water of relatively wide ranging chemical composition. However there are plants that are particularly sensitive to specific water quality parameters [46].

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts are present in irrigation water in relatively small amounts but their effects are significant. They originate from dissolution or weathering of the rocks and soil; including dissolution of lime, gypsum and other slowly dissolved soil minerals. These salts are carried with the water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop [47].

The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use [47].

The problems that result vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems [47].

Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity. Soil scientists use the following categories to describe irrigation water effects on crop production and soil quality [48]:

- Salinity hazard - total soluble salt content
- Sodium hazard - relative proportion of Na^+ to Ca^{2+} and Mg^{2+} ions
- pH
- Alkalinity - carbonate and bicarbonate
- Specific ions (chloride, sulfate, nitrate) and boron

Other potential irrigation water contaminants that may affect suitability for agricultural use include heavy metals and microbial contaminants.

1.2.1. Water Salinity

This is also referred to as total dissolved solids (TDS). The total concentration of salts dissolved in water (salinity) directly affects plant growth by either specific ion toxicity or as a general salinity effect by reducing the availability of water to the plant. Sometimes plant growth reduction caused by salinity is so suitable and may go unnoticed by growers. However, several ornamental plants are adversely affected by mild salinity [46].

The most practical way to measure salinity is by EC. The availability of water to conduct an electrical current is directly related to the concentration of salts present in the solution. The higher the EC, the higher the salt content and the less the water is desirable for plant growth. Water with an EC greater than 1.0 dS/m would be considered to have a high salinity hazard [46].

If source of water has an EC greater than 1.0 dS/m, action must be taken to reduce the salinity. Many growers blend water from two sources (one with high salinity and one with low salinity) to obtain proper salinity. A last resort would be the use of reverse osmosis [46].

1.2.2. Sodium Hazard

While EC is an assessment of all soluble salts in a sample, sodium hazard is defined separately because of sodium’s specific detrimental effects on soil physical properties [48].

The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium Na^+ to Ca^{2+} and Mg^{2+} ions in a water sample. Calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles. This dispersed soil will readily crust and have water infiltration and permeability problems. Sodium in irrigation water can also cause toxicity problems for some crops, especially when sprinkler applied [48].

High concentrations of sodium in irrigation water can result in the degradation of soil structure. This will reduce water infiltration into the soil surface and down the profile, and limit aeration, leading to reduced crop growth [48].

1.2.3. Water pH

pH has no direct effect on plant growth. However, pH does affect the availability of nutrient elements in irrigation water, fertilizer solutions and the growing medium.

The pH of irrigation water should usually be within the range of 5.5 to 6.5. These levels enhance the solubility of most micronutrients and avoid a steady increase in the pH of the growing medium. This pH range also optimizes the solubility of nutrients in concentrated fertilizer stock solutions.

1.2.4. Water Alkalinity

Alkalinity is a measure of the water’s ability to neutralize acidity. An alkalinity test measures the level of bicarbonates, carbonates and hydroxides in water. The results are expressed as mg/L of calcium carbonate ($CaCO_3$). Levels between 30 and 60 mg/L are considered optimum for most plants.

Trace elements deficiencies and imbalances of calcium and magnesium can result from irrigating with high alkalinity water. The problem is more serious when plants are grown in small containers because small volumes of growing media are poorly buffered to pH change.

Carbonates and bicarbonates in high alkalinity water can also clog nozzles of sprayers and drip irrigation systems. These salts will also form unsightly precipitates on leaves. The activity of some pesticides and growth regulators is reduced by high alkalinity [46].

1.2.5. Chloride and Boron in Water

Chloride is essential to plants in very low amounts; it can cause toxicity to sensitive crops at high concentrations. High chloride concentrations cause more problems when applied with sprinkler irrigation. Chlorides in high concentrations can inhibit plant growth. Overhead irrigation can cause leaf burn or leaf drop especially when the rate of evaporation is high. There are differences in tolerance between plant species, but most row crops will tolerate levels less than 200 mg/L [48].

Boron is another element that is essential in low amounts, but toxic at higher concentrations. In fact, toxicity can occur on sensitive crops at concentrations less than 1.0 mg/L [48].

CHAPTER 2

MATERIALS AND METHODS

2.1. REAGENTS AND SOLUTIONS

- **Reagents and solutions for the determination of pH and EC**
  - Buffer solutions-Fisher Scientific (pH= 4, 7 and 10)
  - 0.010 M KCl solution (KCl-Merck, dried at 105 °C, for 2 hours, dissolve 0.746 g in 250 mL of deionized water. Dilute to 1.00 L with deionized water.)
- **Reagents and solutions for the determination of lime content**
  - c. HCl (Panreac- 37 % (w/w), d= 1.19 g/mL, M=36.46 g/mol)
- **Reagents and solutions for the determination of organic matter**
  - 1.0 N $K_2Cr_2O_7$ solution ($K_2Cr_2O_7$ - Carlo Erba Reagents 99 % pure solid, dried at 105 °C, for 2 hours, dissolve 49.04 g in 250 mL of deionized water. Dilute to 1.00 L with deionized water.)
  - c. H_2SO_4 (Merck -98 % (w/w), d=1.84 g/mL, M=98.04 g/mol)
  - 0.16 % (w/v), diphenylamine–4-sulfonic acid barium salt solution (diphenylamine–4-sulfonic acid barium salt-Merck, dissolve 0.160 g in 25 mL of deionized water. Dilute to 100 mL with deionized water.)
  - 0.50 N $FeSO_4$ solution (99.5 % pure $FeSO_4.7H_2O$-Riedal–de Haën, dissolve 114.0 g in 15.0 mL c. H_2SO_4. Dilute to 1 L with deionized water and store in a dark bottle. Standardize with 1.0 N $K_2Cr_2O_7$ solution.)

- **Reagents and solutions for the determination of nitrogen**
  - c. H_2SO_4 (Merck- 98 % (w/w), d=1.84 g/mL, M=98.04 g/mol)
  - c. H_2O_2 (Merck- 35 % (w/w), d=1.13 g/mL)
  - Selenium tablet (Delta Kjeltabs Catalysts- mixture of 3.5 g K_2SO_4 and 0.0035 g Se)
  - 4 % (w/v) boric acid solution (boric acid-Merck, dissolve 40.0 g, in 500 mL deionized water. Dilute to 1.00 L with deionized water.)
  - 50 % (w/w) NaOH solution (dissolve 500 g NaOH, in 500 mL deionized water)
  - 0.050 M H_2SO_4 solution prepared from c. H_2SO_4
  - Methyl red and bromcresol green solution (dissolve 0.020 g methyl red-Merck and 0.100 g bromcresol green-Merck in 100 mL of ethanol)

- **Reagents and solutions for the potassium determination of soil samples**
  - 100 meq/L KCl stock solution (KCl-Merck, dissolve 7.45 ± 0.05 g, previously dried for at least 1 h, at 140 °C in 500 mL of deionized water. Dilute to 1.00 L with deionized water.)
  - c. NH_3 (Merck- 25 % (w/w), d=0.91 g/mL)
  - Glacial acetic acid (Merck-100 % (w/w), d=1.05 g/mL)
  - 1.0 M ammonium acetate solution (ammonium acetate-Merck, dissolve 77.09 g in 700-800 mL deionized water. Adjust the pH 7 with ammonia or acetic acid using a pH meter. Dilute to 1.00 L with deionized water.

    Or; mix 57.0 mL of glacial acetic acid and 68.0 mL of c. ammonia in 600 mL of distilled water. Adjust pH 7.00 using glacial acetic acid or ammonia using a pH meter. Dilute to 1.00 L with deionized water.)

- **Reagents and solutions for the determination of phosphorus**
  - c. HCl (Panreac- 37 % (w/w), d= 1.19 g/mL, M=36.46 g/mol)

- 1.0 M NaOH solution (dissolve 40.0 ±0.1 g NaOH, in 500 mL deionized water. Cool and dilute to 1.00 L with deionized water.)
- 0.50 M $NaHCO_3$ solution ($NaHCO_3$- Riedel-de Haën, dissolve 42.0 g in 950 mL deionized water. Adjust the pH 8.5 with 1.0 M of NaOH or c. HCl using a pH meter. Dilute to 1.00 L with deionized water.)
- 5.0 M H_2SO_4 solution prepared from c. H_2SO_4
- Acid molybdate stock solution (prepare by mixing following solutions and make solution 2.0 L with deionized water in volumetric flask.)
    - 1.00 L of 5.0 M H_2SO_4 solution prepared from c. H_2SO_4
    - 250 mL of ammonium molybdate solution (ammonium molybdate-Merck, dissolve 12.0 g in 250 mL of deionized water)
    - 100 mL of antimony potassium tartrate solution (antimony potassium tartrate-Merck, dissolve 0.2908 g in 100 mL of deionized water)
- Reagent B (ascorbic acid-Merck, dissolve 0.5278 g in 200 mL of the acid molybdate stock solution.)
- 100 mg/L P stock solution (KH_2PO_4 –Merck, dissolve 0.4393 g in 250 mL deionized water. Dilute to 1.00 L with deionized water.)
- 2.5 M H_2SO_4 solution prepared from c. H_2SO_4

Reagents and solutions for the determination of micronutrients

- c. HCl (Panreac- 37 % (w/w), d= 1.19 g/mL, M=36.46 g/mol)
- 1:1 (v/v) HCl solution (mix 500 mL of c. HCl with 500 mL of deionized water)
- 0.0050 M DTPA solution (Dissolve 14.29 g triethanolamine, 1.967 g diethylenetriaminepentaacetic and 1.470 g $CaCl_2$ in 200 mL of deionized water. Dilute to 900 mL with deionized water. Adjust the pH 7.3 with 1:1 (v/v) HCl. Dilute to 1.00 L with deionized water.)
- 1 % (v/v) HNO_3 (dissolve 10 mL of c.HNO_3 in 200 mL of deionized water. Dilute to 1.0 L with deionized water.)

- **Reagents and solutions for the determination of alkalinity**
  - 0.005 M H_2SO_4 solution (prepared from c. H_2SO_4 and standardized with 0.0050 M Na_2CO_3 solution)
  - Phenolphthalein indicator (phenolphthalein-Merck, dissolve 5.0 g in 500 mL of 95 % ethanol.)
  - Methyl orange indicator (methyl orange-Merck, dissolve 0.10 g in 100 mL of deionized water.)

- **Reagents and solutions for the determination of chloride**
  - 0.050 M $AgNO_3$ solution ($AgNO_3$-Merck, dissolve 8.4944 g in 100 mL of deionized water. Dilute to 1.0 L with deionized water. Standardize with 0.01 M NaCl solution.)
  - 0.01 M NaCl solution (NaCl-Merck, previously dried for at least 1 h, at 250-350 °C, dissolve 0.5844 g in 500 mL of deionized water. Dilute to 1.00 L with deionized water.)
  - 5 % (w/v), potassium chromate solution (K_2CrO_4- Merck, dissolve 5.0 g in 75 mL of deionized water. Add 0.050 M $AgNO_3$ solution until red precipitate occurs. Let stand 12 h, filter and dilute to 100.0 mL with deionized water.)

- **Reagents and solutions for the determination of calcium and magnesium**
  - 0.005 M of EDTA solution (dissolve 2.0 g EDTA Disodium Salt Dehydrates (Titriplex III)-Merck and 0.05 g $MgCl_2.6H_2O$ in 250 mL of deionized water. Dilute to 1.00 L with deionized water.)
  - Eriochrome Black T indicator (dissolve 0.50 g Eriochrome Black T-Merck and 4.5 g hydroxylamine hydrochloride-Merck, in 100 mL of 95 % ethanol)
  - Murexide indicator (Mix 200 mg murexide-Merck with 100 g of solid NaCl- Merck. Grind the mixture to 40 to 50 meshes.)
  - 4.0 M NaOH solution (dissolve 160.0 ±0.1 g NaOH, in 500 mL deionized water. Cool and dilute to 1.00 L with deionized water.

- c. NH_3 (Merck- 25 % (w/w), d=0.91 g/mL)
- NH_4Cl (Merck)
- pH 10 buffer solution (mix 67.5 g NH_4Cl and 570 mL c.NH_3 to make 1.00 L of solution)

- **Reagents and solutions for the determination of sodium**

  - 145 meq/L of NaCl stock solution (NaCl-Merck, previously dried for at least 1 h, at 140 °C, dissolve 8.475 g $\pm$ 0.005 g in 500 mL of deionized water. Dilute to 1.00 L with deionized water.)

- **Reagents and solutions for the determination of boron**

  - 100 mg/L boron stock solution (H_3BO_3–Merck, dissolve 0.5716 $\pm$ 0,0005 g in 250 mL of deionized water. Dilute to 1.00 L with deionized water.)
  - Carmine solution (dissolve 0.920 g of carmine in 100 mL of c. H_2SO_4 solution. Dilute to 1.00 L with H_2SO_4.)

2.2. INSTRUMENTATION AND APPARATUS

The following apparatus and instruments were used for the preparation of soil and determination soil and water quality parameters. The details of the instruments will be given in the related sections.

- Retsch 2-mm sieve for mechanical or manual, wet or dry sieving (D × H 200 mm × 50 mm/ Quintuple tested and provided with Quality Certificate DIN ISO 3310/1) was used for sieving the soil.
- Automatic burette was used for the determination of saturation percentage of soil samples.
- EcoMeT P 25 pH meter was used for pH measurements of soil samples.
- Orion Model 720-A pH meter with the combined electrode was used for pH measurements of water samples.

- Thermo Orion 3 Star pH meter with the combined electrode was used to measure pH values of soil samples for the determination of phosphorus.
- Jenway Model 4520 Laboratory Conductivity/TDS Meter was used for the measurements of EC of soil samples.
- Jenway Model 4510 Laboratory Conductivity/TDS Meter was used for the measurements of EC of water samples.
- Scheibler Calcimeter was used for determination of lime content of soil samples.
- Velp DK 20 heating digester and Velp UDK 142 fully automatic distillation unit were used for the determination of nitrogen concentration of soil samples.

Figure 2.1. VELP UDK Automatic distillation unit

- Jenway PFP7 flame photometer was used for determination of sodium and potassium concentrations of soil and water samples.
- Jenway 6300 UV-VIS spectrophotometer was used for determination of phosphorous concentration of soil samples.
- Shimadzu UV-2100 spectrophotometer was used for determination of boron concentration of water samples.

2.3. ANALYSIS OF SOILS

A soil analysis is used to determine the level of nutrients found in a soil sample. As such, it can only be as accurate as the sample taken in a particular field. The results of a soil analysis provide the agricultural producer with an estimate of the amount of fertilizer nutrients needed to supplement those in the soil [49]. Soil chemical analysis deals with determinations of with over 60 of the naturally occurring chemical elements. Additional soil elements continually become of interest in plant nutrition, in addition relation to essentiality or toxicity, or for physiological substitution [50].

In this study, soil samples have been collected from Güneşköy, at Hisarköy, in Kırıkkale for the soil analysis. The soil electrical conductivity (EC) was measured with conductivity meter and pH with pH meter. Organic matter content was determined by volumetry. Scheibler Calcimeter was used for the determination of lime content of the soil. Nitrogen percentage of the soil was determined using automatic Kjeldahl instrument. Sodium and potassium concentrations were determined with flame photometer, phosphorus with spectrophotometer and micronutrients with inductively coupled plasma optical emission spectrometer (ICP-OES).

The reference soil is the soil with several constituents were determined and established by Soil-Fertilizer and Water Resources Central Research Institute Laboratory. This reference soil was analyzed similar to the soil samples collected from Güneşköy.

2.3.1. Collection and Preparation of Soil Samples

Proper sampling and analytical techniques are critical for accurate determination of the nutrient content and other properties of soils. Ten samples should be taken per two hectares (ha) or 20 decares (da) of land in a diagonal pattern for collecting a composite sample (Figure 2.2) [51].

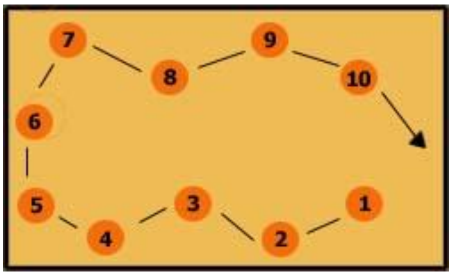

Figure 2.2. Soil sampling plan of a field

First, in this study sample collection of field was planned before sample collection. Six soil samples were collected separately from different fields in Güneşköy. Soil samples were taken using a spade. The area of the sampling was cleaned from herb and plant remains. The shovel was dipped up to 20-cm depth. A pit was opened with a shovel. Soil samples were obtained about the 2-cm of thickness, 3–4-cm width and 20-cm length of the part of soil. Collecting scheme of soil sample is shown in Figure 2.3. Approximately, 1 kg of soil sample was collected and placed in a plastic bag and then mixed. The bag was turned around a few times, in order to make the soil homogeneous. Plant residues and stone pieces were removed by hand and then soil sample was transferred to sample bag. Sampling date, location of the sampling and sampling number were marked on the bags and soil samples were brought to the laboratory [51].

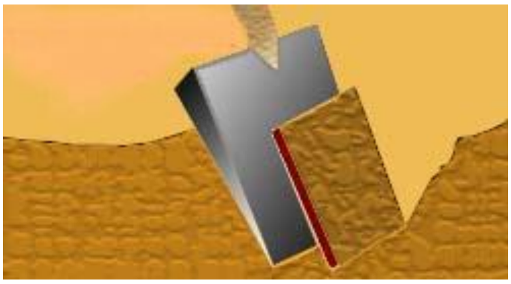

Figure 2.3. Soil collection scheme

After bringing to the laboratory each soil sample was air-dried on a layer of filter paper. Then dried samples were once more cleaned off stones and plant residues. The soil samples were kept for at least 5 days before being tested, and then crushed manually in a mortar. Each soil sample was sieved through a 2-mm sieve (Figure 2.4). Sieved samples were collected, sub-sampled (500 g), and stored in clean plastic bottles [51].

Figure 2.4. Sieving of the soil

In this study first soil pH, soil salinity, lime content and soil texture (saturation percentage) were determined. Then soil organic matter and nitrogen, potassium, phosphorus, zinc, iron, manganese and copper content were determined.

2.3.2. Saturation Percentage and Determination of Soil Texture

Saturation percentage of soil is used for determination of approximate soil structure. A 100-g of soil sample was weighed into a porcelain pot and water was added drop by drop with an automatic burette. At the same time the soil was stirred with a spatula to obtain a saturation mud. At the saturation, the surface of the mud should be bright and when the center of mud is opened by the spatula in the porcelain pot, the surface of the mud should be covered up immediately. Then volume of the added water was recorded [15,52].

Then the mud was kept in a 150-mL plastic beaker overnight. If the saturation mud is dried and not bright, water should be added drop by drop with an automatic burette. Then, volume (V) of water spent totally for saturation was recorded, V in mL. The saturation percentage is obtained by addition of 0.1 x V to the total volume [15,52].

% Saturation = V + 0.1 × V

2.3.3. Measurement of Soil Electrical Conductivity

Electrical conductivity (EC) indicates the amount of soluble (salt) ions in the soil. The determination of EC was made with a conductivity cell by measuring the electrical resistance of the soil suspensions [15,53].

In this study Jenway Model 4520 Laboratory Conductivity/TDS Meter was used for the measurements of EC of soil samples at an interval between 0 and 1999 μS/cm, with a resolution 1 μS/cm. It compensates the temperature automatically.

For EC measurements 0.010 M of potassium chloride was used as a reference solution. The electrical conductivity of 0.010 M KCl solution was measured at the same temperature as the soil suspensions. It has an electrical conductivity of 1413 μS/cm at 25 °C. EC meter was calibrated with this solution before measurement of the electrical conductivity of soil suspensions prepared for determination of % saturation. The conductivity cell was filled with the soil suspension. Then it was shaken to settle the suspension and further additions of suspension were done until the cell was completely full. The conductivity was measured as μS /cm on the conductivity meter. Total salt (%) can be calculated using the following equation [15,53]:

$$\text{\% Total salt} = \frac{EC(dS/m) \times 0.064 \times \%\,\mathrm{saturation\,(mL)}}{100}$$

1000 μS /cm = 1 dS /m

2.3.4. Measurement of Soil pH

The pH of a soil significantly affects plant growth, primarily due to the change in availability of both the essential elements, such as P, and most of micronutrients, Cu, Fe, Mn, Mo, and Zn, as well as nonessential elements, such as Al, that can be toxic at elevated concentrations [54].

The pH in the saturated soil was measured with the help of combination pH electrode and pH meter standardized against known buffer solutions (pH= 4, 7 and 10). EcoMeT P 25 pH meter was used for pH measurements between 0.00 and 14.00 with a resolution 0.01. It has combination pH electrode where a single cylinder contains both the reference electrode and a glass membrane electrode. It can be calibrated manually or automatically at three points. The water –saturated soil was taken for measurement of pH in the stirred suspension, at 20 ± 2 °C. The stirring of suspension should be at such a rate to achieve a reasonably homogeneous suspension of the soil particles; but entrainment of air should be avoided. After the pH stabilization, the pH values were recorded with two decimal places [50,55].

2.3.5. Determination of Lime Content

The Scheibler Method involves the determination of the carbonate content of the soil based on a volumetric method. Scheibler Calcimeter was used for this study and it is shown in Figure 2.5. Scheibler Calcimeter consists of a glass tube and a burette connected with plastic tubing and they are filled with water. There is a weight and a bottle for the adjustment of water level. The carbonates present in the soil sample were converted into CO_2 by adding hydrochloric acid to the sample while atmospheric temperature and pressure were recorded. The reaction in simplified form reads as follows [15,56,57]:

$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$

$H_2CO_3 \rightarrow H_2O + CO_2\,(g)$

CO_2 released as a result of above reaction causes the water to rise. The height of water level is measured as an indication for the released quantity of CO_2, from which the carbonate content can be calculated. The carbonate content is expressed as % (w/w) calcium carbonate content. All the determinations are carried out under the same conditions [15,56,57].

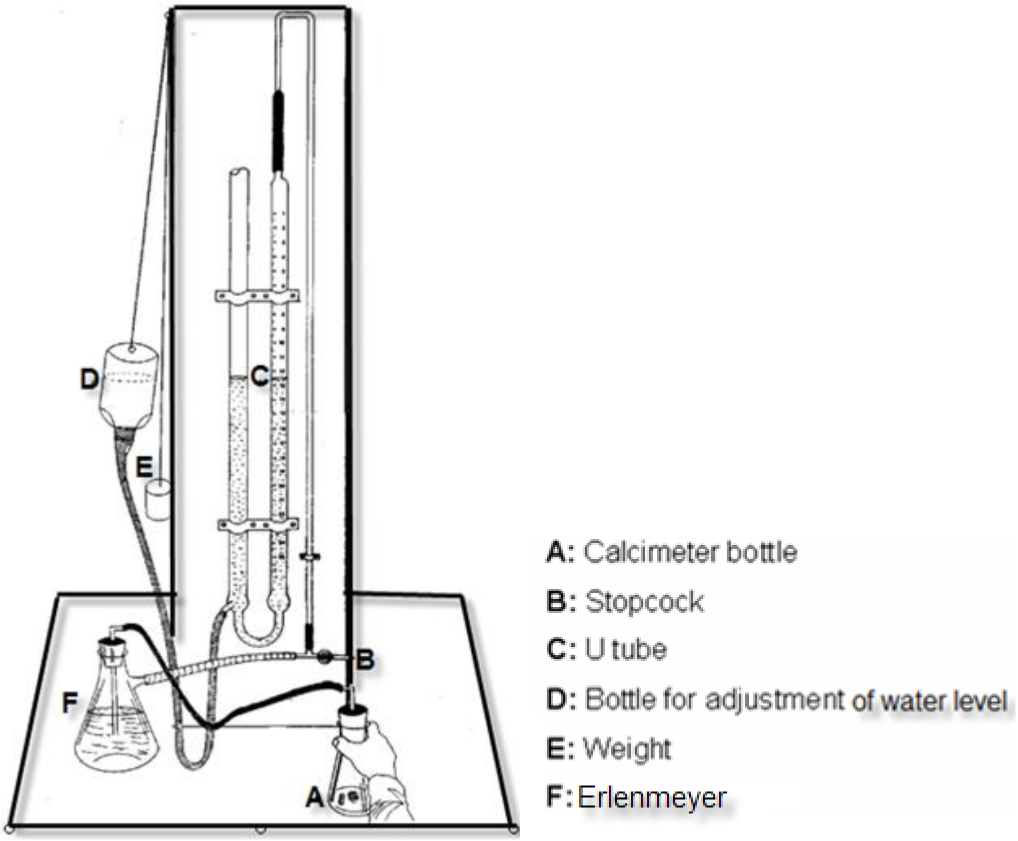

Figure 2.5. Scheibler Calcimeter

In this study about 1.0 g of soil sample accurately was weighed and placed into the Calcimeter bottle. At the same time a plastic cup was filled with 5.0 mL of c. HCl. The cup containing the acid was placed in the reaction vessel containing the soil sample using tongs. There is no contact between the hydrochloric acid and the soil before the reaction vessel is connected to the Scheibler unit. The apparatus was closed with the rubber stoppers and connected the reaction vessels. Stopcock (B) was closed and the water level was checked once again to be equal in the arms of glass U-tube [15,56,57].

Calcimeter bottle was carefully shaken for 5 min for the reaction of the hydrochloric acid with soil from the cup. The gas produced would lower the water level in the tube on the right and at the same time would raise the water level in the tube on the left. During shaking, care was taken for water not to spill from U tube by adjusting the bottle filled water which was attached to a weight, as shown in Figure 2.6. At the end of the shaking period, when there are no further bubbles in the erlenmeyer flask, it is decided that reaction has stopped. The water level was adjusted in two arms of the U tube. At the same time the level of the water in burette and the pressure and temperature of the laboratory environment were recorded [15,56,57].

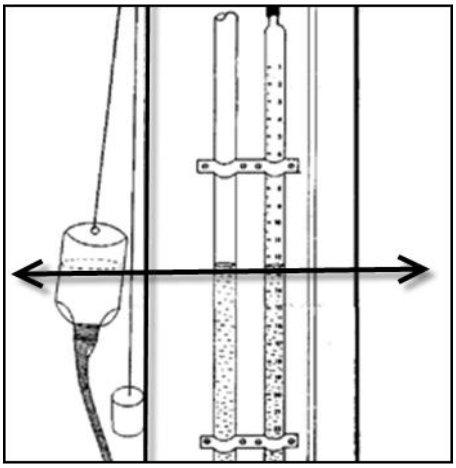

Figure 2.6. Adjustment water level in Calcimeter

The calculation of lime % of soil samples is done using the following equations.

V_0: Volume of the CO_2 at STP (cm^3)

$$V_0 = \frac{V_T (P_A - P_V) \times 273}{760 \times (273 + t)}$$

V_T : Volume of gas measured in Calcimeter (cm^3)

P_A: atmospheric pressure (mmHg)

P_V: vapor pressure (mmHg) at measured t°C

$$\% \text{ (w/w) Lime} = \frac{\left(\frac{V_0 \times 10^{-3}}{22.4} \times 100.087 \right) g}{m_{SAMPLE}(g)} \times 100$$

$$\% \text{ (w/w) Lime } = \frac{V_0 \times 0.4468}{m_{SAMPLE}}$$

2.3.6. Determination of Organic Matter

The Walkley-Black wet-chemical oxidation technique yields direct determination of organic matter in the soil. However, it requires the use of potassium dichromate, and disposal of the waste is problematic. For calcareous soil samples, the Walkley-Black procedure should be preceded by removal of carbonates using strong-acid digestion. Heating the sample to 150ºC, using a hot plate increases the efficiency and precision of the dichromate digestion. Typically, in Walkley-Black determinations of organic matter, organic carbon is determined and it is converted to organic matter using the Van Bemmelen correction factor of (100/58=1.724) which assumes soil organic matter is 58 % (w/w) carbon [58].

In this study the Walkley-Black procedure was used for determination of soil organic matter. In this procedure, 10.0 mL of 1.0 N $K_2Cr_2O_7$ solution (prepared according to procedure given in Section 2.1.1) and 20.0 mL of c.H_2SO_4 were added to 1.0 g of soil. The solution was swirled and allowed to cool (when the potassium dichromate and sulfuric acid were mixed the exothermic reaction occurs). The solution was left for 1 minute on a hot plate at 150ºC. If the color of solution is green, another 10.0 mL of 1.0 N $K_2Cr_2O_7$ should be added and the same procedure can be applied [15,59]. A 200.0 mL of water and 12–13 drops of 0.16 % diphenylamine-4-sulfonic acid barium salt solution were added as an indicator to the cooled sample [15].

The equation of this reaction is as follows:

$$\mathbf{2Cr_2O_7^{\,2-} + 3C + 16H^+ \rightarrow 4Cr^{\,3+} + 3CO_2 + 8H_2O}$$

The excess $Cr_2O_7^{2-}$ was back titrated with 0.50 N $FeSO_4$ solution according to procedure given in [15] and using diphenylamine–4-sulfonic acid barium salt indicator until color changes from blue to green in the sample.

The equation of titration reaction is as follows [60]:

$$\mathbf{Cr_2O_7^{\,2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{\,3+} + 6Fe^{3+} + 7H_2O}$$

$FeSO_4$ solution was standardized against 10.0 mL of 1.0 N $K_2Cr_2O_7$ solution. Titration was performed similar to sample solution. The total organic matter was calculated using the following equations [15,59].

N_K= Exact normality of $FeSO_4$
V_1=Volume of $FeSO_4$ used to titrate10.0 mL of 1.0 N $K_2Cr_2O_7$
$N_K=10.0/V_1$

% (w/w) Organic Carbon = $(V_A \times 1.0 - V_B \times N_K) \times 0.337 / m$ (g)

V_A = Volume of 1.0 N $K_2Cr_2O_7$ added to the sample (10.0 mL)
V_B = Volume of $FeSO_4$ used to titrate excess $K_2Cr_2O_7$

$$0.337=\frac{3\times 100}{1000\times 0.89}$$

In this method, it was assumed 89 % of carbon was oxidized in the sample Equivalent weight of carbon 12 / 4 =3 g/eq, Multiplication with 100 to find % (w/w) carbon and division of 1000 convert mg to g

% (w/w) Organic Matter = % (w/w) Organic Carbon × F

F: 1.724 (Van Bemmelen Factor), assuming organic matter contains 58 % (w/w) organic carbon.

2.3.7. Nitrogen Determination

The Kjeldahl method was developed in 1883 by a brewer called Johann Kjeldahl. A small quantity of food sample is digested with a strong acid, often c. H_2SO_4 so that it releases ammonium ions which can be determined by a suitable titration technique. The amount of protein present is then calculated from the nitrogen concentration of the food. The same basic approach is still used for determination of nitrogen in food and agricultural analysis today, although a number of improvements have been made to speed up the process and to obtain more accurate measurements.

The Kjeldahl method can be conveniently divided into three steps: digestion, neutralization and titration. For this study soil nitrogen was determined with Kjeldahl method using heating digester and fully automatic distillation unit in three steps [61].

- **Digestion**

A 1.0 g of soil sample was weighed into a digestion flask. Then 10.0 mL of c.H_2SO_4 for the digestion of the soil and 5.0 mL of c.H_2O_2 that is an oxidizing agent were added to the sample. The soil sample can be digested using a catalyst, such as copper, selenium, titanium, or mercury (to speed up the reaction) by heating at 400°C on a Velp DK 20 heating digester [62].

In this study selenium tablet was used for digestion which converted any nitrogen in the soil (other than that which is in the form of nitrates or nitrites) into $NH_4^+$and other organic matter to CO_2 and H_2O. Ammonia gas was not liberated in an acid solution because the ammonia was in the form of the ammonium ion (NH_4^+) which is attached to the sulfate ion (SO_4^{2-}) and thus remained in solution [61].

The digested soil sample was cooled. Then 10.0 mL of water were added to sample solution. According to following reaction N is converted to $(NH_4)_2SO_4$ in the sample.

$$\textbf{Organic Matter (C, N, S)} + H_2SO_4 \rightarrow (NH_4)_2SO_4\,(aq) + CO_2\,(g) + SO_2\,(g) + H_2O\,(g)$$

- **Neutralization**

After the digestion has been completed the digestion flask was connected to a Velp UDK 142 fully automatic distillation unit Figure 2.6 [61]. In distillation unit 50.0 mL of 4 % (w/v) of H_3BO_3, 50.0 mL of 50 % (w/v) of NaOH and 40.0 mL of H_2O were added automatically to sample solution to make the solution alkaline [62]. Sodium hydroxide converts the ammonium sulfate into ammonia gas [61].

$$(NH_4)_2SO_4 + 2\,NaOH \rightarrow 2NH_3 + 2H_2O + Na_2SO_4$$

After, the ammonia gas that has been formed, it was liberated from the solution and was carried out of the digestion flask, into the distillation unit which contained excess of 4 % (w/v) H_3BO_3. The solution in the distillation unit converted the ammonia gas into the ammonium ion, and simultaneously converted the boric acid into the borate ion [61].

$$NH_3 + H_3BO_3 \rightarrow NH_4^+ + H_2BO_3^-$$

- **Titration**

The nitrogen content was then estimated by titration of the borate ion formed with 0.050 M H_2SO_4 solution, using 5 drops of mixture of methyl red and bromcresol green solution as an indicator which changes color from blue to red at pH 4.4 to signal the end-point of the reaction [62].

$$H_2BO_3^- + H^+ \rightarrow H_3BO_3$$

The mmoles of acid required to reach the end-point is equivalent to the mmoles nitrogen that was in the soil sample [61]. The similar procedure was applied to the blank solution in order to calculate corrected total nitrogen content in the soil samples. The soil nitrogen was calculated using following equation [15].

$$\% \text{ (w/w) Total N} = \frac{\left[V_{SAMPLE}(mL) - V_{BLANK}(mL)\ \right] \times M_{H_2SO_4} \times 2 \times 0.014}{m_{SAMPLE}(g)} \times 100$$

$$\% \text{ (w/w) Total N} = \frac{\left[V_{SAMPLE}(mL) - V_{BLANK}(mL)\ \right] \times M_{H_2SO_4} \times 2 \times 14}{m_{SAMPLE}(g) \times 1000} \times 100$$

2.3.8. Potassium Determination

Ammonium acetate extraction is used to asses the amount of plant available potassium. 1.0 M ammonium acetate extraction method at a pH=7 is the most widely used procedure to extract the water soluble and rapidly exchangeable fractions of alkali and alkaline earth cations (Na, Li, Ba, Sr, Ca and Mg) by displacement with NH_4^+ ion. After filtration of the extracts, the concentration of K, Na and Li are determined by the flame photometer [17].

First the calibration curve was plotted using the standard solutions of potassium (Figure 2.7). 0.0 meq/L, 0.25 meq/L, 0.50 meq/L, 1.0 meq/L, 1.6 meq/L, 2.0 meq/L and 3.0 meq/L standard solutions were prepared using 100 meq/L of stock solution to measure K emissions in Jenway PFP7 flame photometer [15,17].

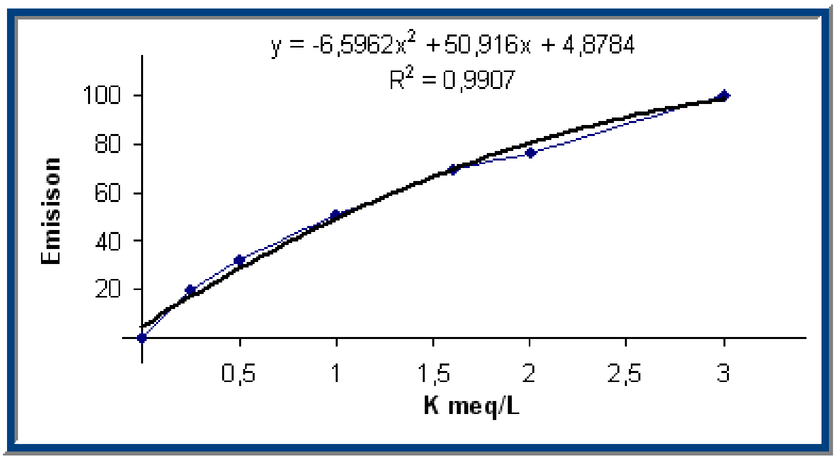

Figure 2.7. Calibration curve for determination of soil potassium

In this study available potassium in the soil samples was extracted with 1.0 M ammonium acetate solution at the pH 7 (Section 2.1.1). 10.0 g of soil sample was weighed and mixed with 25.0 mL of 1.0 M ammonium acetate solution and then was left overnight. Then it was filtered with the help of a vacuum pump. Extraction was repeated three times by addition of 25.0 mL of ammonium acetate solution in each extraction, filtering under vacuum. Then the final volume of extracted portions completed to 100.0 mL. Then K^+ concentrations in soil extracts were measured by flame photometer at 766.5 nm. The results were calculated by prepared calibration curve using the potassium standards [63,64]. For the determination of potassium in soil samples following equations are applied [15].

A: meq K /L from calibration curve

In 10 g soil =A/10 meq K (in the calibration curve K concentrations are meq/L, but 10 g soil samples were extracted in 100 mL ammonium acetate)

In 1000 g soil = A x 10 meq K

In 1 kg soil = A x 10 x 39 mg K = A x 390 mg K

1 da = 250 000 kg

In 1 da soil = A x 97.5 kg K /da

In 1 da soil = A x 117 kg K_2O /da

2.3.9. Phosphorus Determination

In this study, Murphy and Riley Method was used for determination of available phosphorus (ortho-phosphate) in the digest and extracts of soil samples. This method estimates the relative bioavailability of ortho-phosphate using $NaHCO_3$ extraction and uses the blue color development by the molybdophosphate complex reduced by the ascorbic acid in the presence of antimony to estimate the concentration of P in soil solution [17].

0.50 M $NaHCO_3$ extraction solution was prepared in a plastic bottle. The pH of extracting solution was adjusted to 8.5 with 1.0 M NaOH and/ or c. HCl using Thermo Orion 3 Star pH meter [65]. In the process of extraction, CO_2 from bicarbonate is driven off, pH increases and bicarbonate is converted to carbonate. Thus when there is lower calcium activity, calcium carbonate forms, increasing the quantity of phosphate in the solution [66].

Ortho-phosphoric-P is determined using spectrophotometer at 882 nm. Phosphorous reacts with molybdic acid and forms blue-colored complex**.** The molybdenum blue reaction must be carried out under well-defined conditions of pH, temperature and reaction time to move equilibrium towards the most condensed forms, such as a maximum of 12 atoms of molybdenum can surround the P atom. The reaction consists in combining molybdic acid with ortho form of P. This condensation can only be carried out in acidic medium. A reducing compound (ascorbic acid) catalyzed by the antimony tartrate leads to the formation of the blue colored complex of phosphomolybdic acid anion [64]. Ascorbic acid combined with potassium antimony tartrate has a strong catalytic power in cold acidic medium. It enables an intense blue complex to be obtained that is stable for 24 h [67]. Reaction is given below:

$$\mathbf{HPO_4^{2-} + 12MoO_4^{2-} + 23\,H^+ \rightarrow \underline{[PO_4(MoO_3)_{12}]^{3-}}_{\text{Blue reduced form}} + 12\,H_2O}$$

In this study, acid molybdate stock solution was prepared by mixing three solutions; sulfuric acid, ammonium molybdate and antimony potassium tartrate solutions. Reagent B is ascorbic acid dissolved in 200 mL of the acid molybdate solution prepared (Section 2.1.1) [15].

100.0 mL of intermediate P standard solutions (1.0 mg/L, 10.0 mg/L P) were prepared using 100.0 mg/L P stock solution. Then 1.0, 2.0, 3.0, 4.0 and 5.0 mL of solutions were pipetted from 1.0 mg/L and 1.0, 2.0, 3.0 mL solutions were pipetted from 10.0 mg/L intermediate P solutions into 25 mL of volumetric flasks [15]. 5.0 mL of 0.50 M $NaHCO_3$ solution were added to each flask. The pH of the standards should be lowered from 8.5 to 5.0 using 2.5 M H_2SO_4 solution. Approximate volume of 2.5 M H_2SO_4 solution is around 0.5–0.9 mL. The volume of 2.5 M H_2SO_4 solution that would be added to standards were determined daily, by taking 5.0 mL of 0.50 M $NaHCO_3$ solution and adding 2.5 M H_2SO_4 solution. Then the determined volume of 2.5 M H_2SO_4 solution was added and they were swirled until all of the CO_2 was removed. Then 4.0 mL of reagent B (sulphuric acid-acid molybdate, antimony potassium tartrate- ascorbic acid) were added to each flask. The volume was made to 25.0 mL with distilled water [42].

Calibration curve was plotted using daily prepared standard solutions. Calibration curve is given Figure 2.8. The absorbance values of standards were read after 0 and 100 % T adjustments with Jenway 6300 UV-VIS spectrophotometer at a wavelength of 882 nm, 10 minutes after mixing the reagents [68].

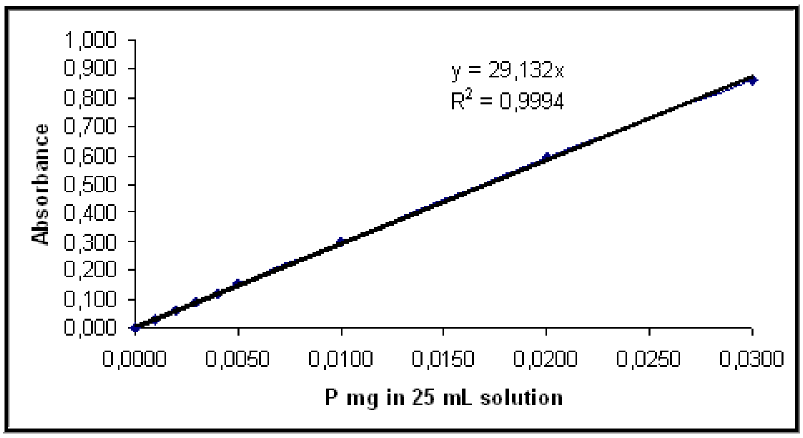

Figure 2.8. Calibration curve of standard P solutions

For the phosphorous determination of soil samples, 100.0 mL of 0.5 M $NaHCO_3$ were added to 5.0 g of dry soil sample. The samples were placed in extraction vessels and they were shaken at 120 cycles /min on electrical shaker for thirty minutes. Suspensions were filtered with Whatman 42 filter paper within one minute and the solution was refiltered if filtrate is cloudy. Previously determined volume of 2.5 M H_2SO_4 was added to 5.0 mL of soil extract pipetted to lower pH from 8.5 to 5.0 in 25.0 mL flask. Each soil extract in the volumetric flask was swirled until all of the CO_2 was removed. To the extract, 4 mL of reagent B was added to get 25.0 mL of solution with deionized water. The absorbance values of soil extracts were read after 0 % and 100 % T adjustments using UV-VIS spectrophotometer at a wavelength of 882 nm [42].

For the determination of phosphorus in soil samples following equations are applied [15].

A: (mg) P from calibration curve

P concentration in soil, in ppm = A x DF

$$DF = \frac{B \times 1000}{m \times n}$$

B: Volume of extraction solution, 100.0 mL

m: mass of soil sample, 5.0 g

n: Volume of extract, 5.0 mL

DF: 4000

In soil, P concentration (ppm)= A x 4000

In soil, P_2O_5, ppm = $A \times 4000 \times \frac{142}{62}$ = A x 9160

1 da soil ~250000 kg

$$kgP_2O_5 / da = \frac{A \times 9160 mgP_2O_5 \times 250{,}000}{1000 \times 1000}$$

kg P_2O_5 / da= A x 2290

2.3.10. Determination of Copper, Iron, Manganese and Zinc

Trace elements (copper, iron, manganese and zinc) in soil samples were measured using a buffered diethylenetriaminepentaacetic acid (DTPA) solution. This method mainly applies to the estimation of the availability of copper, iron, manganese and zinc to plants [69].

The theoretical basis for the DTPA extraction is in the equilibrium of the metal in the soil with the chelating agent. A pH level of 7.3 enables DTPA to extract iron and other metals. The use of DTPA as an extraction reagent was developed by Lindsay and Norwell. Cu, Fe, Mn and Zn can be extracted and determined in soil concentrations of 0.1 to 10 mg/L [54].

It is preferably applicable to soils having a pH greater than 6. Potentially toxic elements such as cadmium, chromium, nickel and lead can also be determined in the extracts. In soils containing large amounts of one or more of these elements, the efficiency of the extraction of any of these elements may be decreased if the complexation capacity of DTPA is exceeded [69].

In this study, for the calibration curve of the micronutrients, a 100-mL of intermediate standard solution containing 100, 100, 20, 40 mg/L of Fe, Cu, Zn, and Mn, respectively, was prepared using 1000 mg/L stock solutions. Then five different mixed standard solutions of Fe, Cu, Zn, and Mn were prepared, by taking 1.0, 2.0, 3.0, 4.0, and 5.0 mL from the mixed intermediate standard solution and diluting to 100.0 mL [70].

Exactly 20.00 g of soil sample was weighed with a plastic spatula in weighing boat, and then it was transferred into a 250.0 mL volumetric flask. The sample was extracted in 40.0 mL of the 0.0050 M DTPA solution at a temperature of 20 °C. The flasks were covered and shaken for 2 h, at 120 cycles/min, at 20 °C ± 2 °C using electrical shaker. After filtering the supernatant and separation of the phases with 125-mm Whatman 42 filter paper, the extract was collected in a polyethylene bottle. 4.0 mL of soil extracts were diluted with 4.0 mL of 1:1 ratio 1 % HNO_3 water solution. Using the above procedure blanks were prepared daily, taking water instead of soil extract. The determination of trace elements in the standards, blanks and soil extracts were performed using Inductively Coupled Plasma (ICP) by the analysts at Soil, Fertilizer and Water Resources Central Research Institute Laboratory [70].

2.4. WATER ANALYSIS

In this study, irrigation water quality was examined for electrical conductivity (dS/m), pH, chloride, sodium, potassium, carbonate, bicarbonate, boron, calcium, magnesium, and sulfate determinations.

2.4.1. Collection and Preparation of Water Samples

The sampling of irrigation water was realized with purging wells and taps. Samples must represent the water supply being sampled. Well water samples should be taken after water is pumped at least 30 minutes. The samples were collected in a clean plastic or glass bottle. The bottle was rinsed at least three times with the water being sampled [71]. Handling, preservation, and storage of the water samples should be adapted to the properties of the chemicals of the interest and the effort invested should be to obtain the necessary information with such resources as are available [72].

For chemical analysis approximately 1.5 L of water sample was taken in a Polyethylene Terephthalate (PET) bottles and they were covered quickly to prevent contact with air. The samples location was labeled on bottle. The date and time of sampling were recorded [73].

Four water samples (Ankara-Sincan-1, Kırıkkale-Güneşköy 1-2-3) were collected and analyzed for irrigation and drinking water quality parameters. There were 18 water samples which were brought to Soil, Fertilizer and Water Resources Central Research Institute Laboratory by the farmers and these water samples were also analyzed for irrigation water quality parameters.

2.4.2. Measurement of Water EC

Water EC was measured using Jenway 4510 EC meter. This conductivity meter measures from 0 to 19.99 μS, 0 to 199.9 μS, 0 to 1999 μS, 0 to 19.99 mS, 0 to 199.9 mS and 0 to 1999 mS with a resolution from 0.01 μS, 0.1 μS, 1 μS, 0.01 mS, 0.1 mS and 1 mS for the measurement of conductivity of water samples. It compensates the temperature automatically.

EC meter was calibrated with 0.01 M KCl solution that has an electrical conductivity of 1413 μS/cm (1000 μS/cm=1 dS/m) at 25 °C before measurement of the electrical conductivity of water samples. The electrical conductivity is a measure of the current conducted by ions present in the water and depends on [74]:

- the concentration of the ions
- the nature of the ions
- the temperature of the solution
- the viscosity of the solution

About 100-mL of water samples were used to measure the EC value. The conductivity measurements were recorded for the determination salinity of water [75].

2.4.3. Measurement of Water pH

The pH of irrigation water sample have been measured using Orion Model 720-A pH meter with the combined electrode as the sensor to determine whether water was acidic, neutral or alkaline. The pH meter and associated electrodes were calibrated against three reference buffer solutions pH=4, 7 and 10. In this measurement a digital laboratory pH Meter with automatic pH calibration, and automatic temperature (slope) correction was used for pH measurements. It has readability as low as 0.01 pH. The true pH of an aqueous solution or extract is affected by the temperature. The temperature effect has been compensated automatically in used instrument.

100.0 mL of irrigation water samples were placed in a clean glass beaker containing a stirring bar. The samples were mixed during the period of pH measurement at a rate that would avoid splashing and loss or gain of acidic or basic gases by interaction with the atmosphere. The electrode was inserted for determination of pH values. Then pH values water samples were measured [76,77].

2.4.4. Determination of Alkalinity (Carbonate and Bicarbonate Ions)

Alkalinity of natural and waste waters is primarily related to carbonate, bicarbonate and hydroxide content of water. It is taken as an indication of the concentration of these components [78]. In this study determination of alkalinity is based on titration of sample bicarbonate and carbonate with 0.0050 M H_2SO_4 solution.

Alkalinity of measurement of samples having an alkalinity level between 0.40 and 20 mmol/L can be performed by acid-base titration [79]. For water samples with higher alkalinity, a smaller test portion can be taken and diluted before the analysis. The titration reactions are as follows:

$$\mathbf{2Na_2CO_3 + H_2SO_4 \rightarrow 2NaHCO_3 + Na_2SO_4}$$

$$\mathbf{2NaHCO_3 + H_2SO_4 \rightarrow 2H_2CO_3 + Na_2SO_4}$$

A 5.0 mL of sample in a beaker was titrated with 0.0050 M H_2SO_4 solution to fixed pH endpoint values of 8.2 and 4.4 by using automatic titrator. These endpoints are the selected equivalence points for the determinations carbonate and bicarbonate ions. The pH 8.2, phenolphthalein endpoint approximates to the equivalent concentrations of carbonate and the pH 4.4 (methyl orange) end point approximates the equivalence point for bicarbonate ion and allows for the determination of the total alkalinity of the water [78].

The volume of sulfuric acid in mL was recorded for the water sample. The concentration of CO_3^{2-} and HCO_3^- ions were calculated as follows:

$$\text{mg CO}_3^{2-}/L = \frac{2 \times M_{H_2SO_4} \times V_1(mL) \times 1000}{V_{SAMPLE}(mL)} \times 60$$

V_1: volume of H_2SO_4 (mL) used to reach the phenolphthalein endpoint

$$\text{mg HCO}_3^{-}/L = \frac{2 \times M_{H_2SO_4} \times (V_2 - 2V_1) \times 1000}{V_{SAMPLE}(mL)} \times 61$$

V_2: volume of H_2SO_4 (mL) used to reach the methyl orange endpoint

2.4.5. Chloride Determination in Water

For this study the chloride ion was analyzed by the argentometric precipitation method (Mohr's Method). The argentometric method for the determination of chloride ion in relatively clear water is suitable when its concentration is between 5 mg/L -150 mg/L in the portion titrated [80].

In a neutral or slightly alkaline solution, 5 % potassium chromate solution can be used as an indicator for detections of the end point. Silver chloride is precipitated quantitatively before red silver chromate is formed as shown by the following reactions [78].

$$\mathbf{Ag^+ + Cl^- \rightleftharpoons AgCl\ (s)}$$

$$\mathbf{2Ag^+ + CrO_4^{2-} \rightleftharpoons Ag_2CrO_4\ (s)}$$

Substances in amounts normally found in potable waters will not interfere. Bromide, iodide, and cyanide ions in water register as equivalent chloride concentration. If the sample is highly muddy, 3-mL of $Al(OH)_3$ suspension must be added to 100 mL of sample, when mixture of sample is settled down and it is filtered [78]. In this study, this step is not applied.

A 5.0 mL of water sample was titrated using standard 0.050 M $AgNO_3$. A few drops of 5 % (w/v) potassium chromate was added to the sample and it was titrated with 0.050 M $AgNO_3$ solution till the color turns to reddish brown, in the pH range of 7 to 10 [73].

The concentration of Cl^- ion was calculated as follows [78]:

$$mgCl^- / L = \frac{M_{\mathrm{AgNO_3}} \times V_{\mathrm{AgNO_3}}\ (mL) \times 1000}{V_{\mathrm{SAMPLE}}\ (mL)} \times 35.450$$

2.4.6. Calcium Determination in Water

A titrimetric method using an aqueous solution of the disodium salt of EDTA for the determination of the calcium content of ground water, surface water and drinking water was applied. Titrimetric method can also be used for municipal and industrial raw water, provided they do not contain interfering amounts of heavy metals. It is applicable to waters with calcium concentrations ranging from 2- 100 mg/L (0.05 - 2.5 mmol/L) [81].

In this study the concentration of calcium in water was determined by titration with EDTA. When EDTA is added to water sample, it combines first with the calcium. Calcium can be determined directly, with EDTA, as the pH is made sufficiently high, the magnesium is largely precipitated as the hydroxide and an indicator is used that combines with calcium only [75,78].

$$\mathbf{Ca^{2+} + Y^{4-} \rightleftharpoons CaY^{2-}}$$

In this experiment 5.0 mL of water sample was used for the determination of calcium concentration in water. About 5 drops of 4.0 M of NaOH solution was added to produce a pH 12 to 13. The 0.1 g of murexide indicator that changed color from pink to purple at the end point was used when all off the calcium has been complexed by the 0.005 M of EDTA solution at pH of 12 to 13 [73]. The volume (mL) of 0.005 M of EDTA used in titration was recorded for the water sample.

The concentration of Ca^{2+} ion was calculated as follows:

$$mg\ Ca^{2+}\ /\ L = \frac{M_{Mg-EDTA} \times V_1\ (mL) \times 1000}{V_{\mathrm{SAMPLE}}\ (mL)} \times 40.00$$

V_1: volume of EDTA (mL) used for the determination of calcium

2.4.7. Magnesium Determination in Water

Total calcium and magnesium was determined by complexometric titration of with a 0.005 M of EDTA aqueous solution of the disodium salt of EDTA at pH of 10. In the titration, the EDTA reacts first with the free calcium and magnesium ions in solution. At the equivalence point calcium and magnesium ions that are combined with the indicator Eriochrome Black T, were released and the color of the indicator changed from pink to blue. The pH=10 buffer solution was prepared from NH_4Cl and c.NH_3 [75].

$MIn^- + HY^{3-} \rightleftharpoons HIn^{2-} + MY^{2-}$

Pink blue

The volume (in mL) of EDTA used in the titration was recorded for the water sample. The reactions of Ca^{2+} and Mg^{2+} ions with EDTA solution are given as follows [75]:

$$\mathbf{Ca^{2+} + Y^{4-} \rightleftharpoons CaY^{2-}}$$

$$\mathbf{Mg^{2+} + Y^{4-} \rightleftharpoons MgY^{2-}}$$

The results are calculated as concentration of Ca^{2+} and Mg^{2+} in mg/L. Since the calcium content has been determined separately by using the same standard solution of EDTA, the concentration of magnesium can be calculated from the difference. The concentration of Mg^{2+} ion can be calculated as follows [75]:

Mg^{2+} mmol = (Ca^{2+}+ Mg^{2+}) mmol - mmol Ca^{2+}

$$\text{mg Mg}^{2+}\text{/L} = \frac{M_{EDTA}[\mathrm{V}_2 - \mathrm{V}_1](mL) \times 24 \times 1000}{V_{SAMPLE}}$$

V_1: volume of 0.005 M of EDTA (mL) used for the determination of calcium

V_2: volume of 0.005 M of EDTA (mL) used for the determination of calcium and magnesium

2.4.8. Sodium Determination in Water

Aspiration of the sample into a gas flame of sufficient thermal energy causes emission of sodium characteristic radiation. Measurement of the intensity of sodium emission is done at a wavelength of 589.0 nm. For samples containing higher concentrations of sodium, a smaller test portion was taken for analysis The ions normally present in raw and drinking water do not interfere with the flame emission spectrometric method for sodium and potassium if an ionization suppressant is present [82].

Determination of both Na and K were realized using Jenway PFP 7 Flame Photometer. It is low temperature, single channel flame photometer designed for the routine determinations of Na and K (Ca, Ba and Li optional).

A calibration curve prepared in sodium concentration range from 0.29 meq/L to 2.9 meq/L is shown in Figure 2.9. For the preparation of 145 meq/L sodium chloride stock solution (the solution is stable for at least 6 months in a polyethylene bottle) 8.475 g ± 0.005 g of NaCl was dissolved using distilled water in a 1.0 L volumetric flask and the solution was made up to the mark. For plotting calibration curve, standard solutions in 0.29 meq/L to 2.9 meq/L were prepared using sodium chloride stock solution with final volume of 1.0 L in distilled water (Table 2.1) [73].

Table 2.1. Recipe for preparation of sodium standard solutions

Volume of NaCl stock solution (mL)	Concentration of sodium (meq/L)
20	2.90
18	2.61
16	2.32
14	2.03
12	1.74
10	1.45
8	1.16
4	0.58
2	0.29

For analysis of sodium distilled water was aspirated for adjusting the scale reading to zero deflection (0 %) reading. The 2.9 meq/L standard solution was aspirated adjusting the scale reading to full deflection (100 %) reading [73].

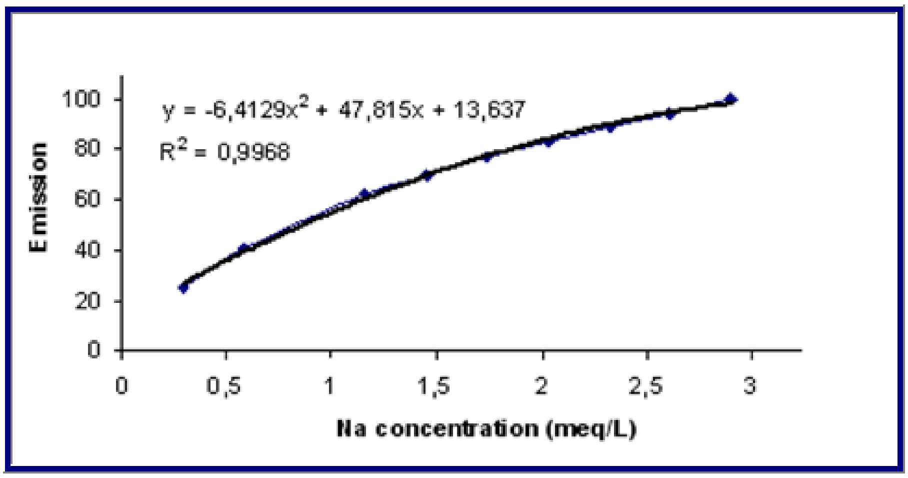

Figure 2.9. Calibration curve for sodium determination

A calibration graph was plotted for sodium. The calibration graph is in general linear but can show a slight curvature, especially when a flame photometer is used. A blank determination was carried out with each batch of samples by applying the same procedure and using distilled water instead of the sample [82]. Then the water samples were aspirated using flame photometer to record the Na emission values. The concentrations of sodium were determined in the sample from the calibration graph.

2.4.9. Potassium Determination in Water

Measurement of the emission intensity for potassium is performed potassium using Jenway PFP7 flame photometer at a wavelength of 766.5 nm. For samples containing high concentrations of potassium, a smaller test portion was taken for analysis [82].

100 meq/L potassium chloride stock solution was prepared from KCl. This solution is stable for at least 6 months in a polyethylene bottle. Potassium standards in 0.20, 0.40, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00 meq/L were prepared daily from the potassium chloride stock solution. The calibration curve is shown in Figure 2.10 [73].

For analysis of potassium distilled water was aspirated for adjusting the scale reading to zero deflection (0 %) reading. The 2.0 meq/L standard solution was aspirated adjusting the scale reading to full deflection (100 %) reading. [73]. Then the water samples were aspirated using a flame photometer to record the emission values. The concentrations of potassium in water samples were determined using the calibration graph.

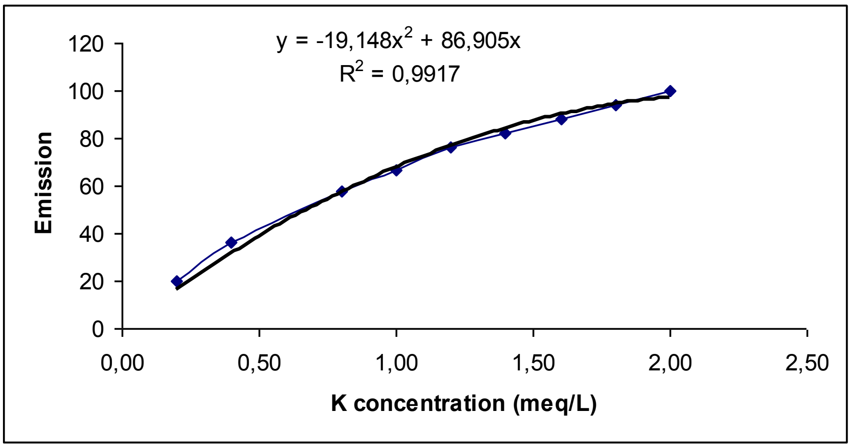

Figure 2.10. Calibration curve for potassium determination

2.4.10. Boron Determination in Water

In this study Carmine Method was applied for the determination of boron concentration in water samples. The Carmine Method is appropriate for the determination of boron in 1 - 10 mg/L range. The range of this method can be extended by dilution or concentration of samples. In the presence of boron, a solution of carmine in concentrated sulfuric acid changes from a bright red to a bluish red or blue, depending on concentration of boron [78].

For the preparation of calibration curve 0 mg/L (blank) , 2 mg/L, 4 mg/L, 6 mg/L, 8 mg/L and 10 mg/L boron solutions were prepared from 100 mg/L boron stock solution. A 1.0 mL from each standard solution was mixed with 1 drop of c. HCl and 5.0 mL of c. H_2SO_4. After 10 minutes, 5.0 mL of carmine solution was added. Then the solutions were kept for 45 minutes until they cooled to room temperature and absorbance of solution was measured by UV-2100 spectrophotometer with a 1.0 cm cell at 585 nm [15]. The absorbance of standard solutions was recorded to plot a calibration curve, Figure 2.11. Water samples were prepared similar to standards. The boron concentrations were found using the calibration curve [75].

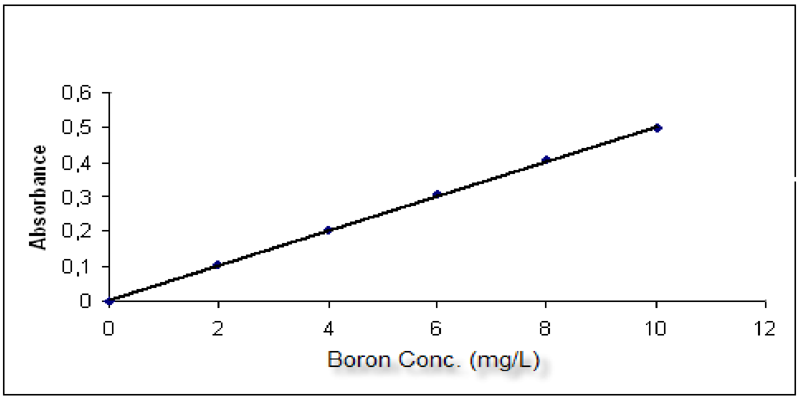

Figure 2.11. Calibration curve for boron determination

CHAPTER 3

RESULTS AND DISCUSSION

3.1. SOIL ANALYSIS RESULTS AND EVALUATION

3.1.1. Results of Analysis of Reference Soil

Reference soil sample number 1422 was prepared by Soil, Fertilizer and Water Resources Central Research Institute Laboratory. Three parallels of reference soil samples were analyzed for the following parameters and the data were obtained as given in Table 3.1.

Table 3.1. Reference soil results and % relative error

Reference Soil	**% saturation**	**pH Values**	**% Total salt**	**K_2O kg/ da**	**% Lime content**	**P_2O_5 kg/ da**	**% Organic matter**
Mean*	74	7.74	0.155	256.28	15.03	11.70	1.04
s*	0	0.01	0.001	2.55	0.17	0.47	0.02
Reference**	72	7.88	0.149	250	16.00	11.50	0.93
% Relative error	2.77	-1.78	4.03	2.51	-6.06	1.74	11.8

* This study

****** Soil, Fertilizer and Water Resources Central Research Institute Laboratory

The % Relative error was found to be changing between 1.74 and 11.8, for P_2O_5 and % organic matter, respectively.

3.1.2. Saturation Percentage and Texture

In this study the soil samples were collected from Güneşköy. The % saturation of soil samples was measured using an automatic burette. The texture of samples was determined using % saturation data. The values of % saturation and corresponding textures of samples are given in Table 3.2.

Table 3.2. % Saturation and textures of soil samples

Güneşköy Soils	Saturation mL Water	+10%	Total Volume mL	Texture
1	54.0	5.4	59.4	Clay Loam
2	48.0	4.8	52.8	Clay Loam
3	45.0	4.5	49.5	Loam
4	56.0	5.6	61.6	Clay Loam
5	45.0	4.5	49.5	Loam
6	55.0	5.5	60.5	Clay Loam

According to % saturation, the texture of samples 1, 2, 4 and 6 are clay loam. Clay loam soil is soil that has up to 25 % clay, 30 to 50 % silt, and the rest is sand. A clay loam soil has good water holding capacity and a good nutrient holding capacity. Its permeability and aeration may be somewhat restricted. Texture of samples 3 and 5 is loam. Loamy soil consists of sand, silt, clay, and organic matter in evenly mixed particles of various sizes. Loamy soil is porous which allows for the best air circulation and retention of moisture. It is suitable for the production of most garden plants because it holds moisture but also drains well so that sufficient air can reach the roots.

3.1.3. EC Values and Salinity

Salinity is a soil property referring to the amount of soluble salt in the soil. Electrical conductivity (EC) is the most common measure of soil salinity and is commonly used for indicating the total concentration of the ionized constituents of solutions. It is closely related to the sum of of the cations (or anions) as determined chemically and usually correlates with total dissolved salt. It is rapid and reasonably precise determination that does not alter or consume any of the samples. The concentration of soluble salts in the soil solution is increased as water is removed from the soil by evaporation and transpiration [83].

Plants are detrimentally affected, both physically and chemically, by excess salts in some soils and by high levels of exchangeable sodium in others. Soils with an accumulation of exchangeable sodium are often characterized by poor tilth (the physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its favorability to seedling emergence and root penetration) and low permeability making them unfavorable for plant growth [83].

By agricultural standards, soils with an EC greater than 4 dS/m are considered saline. In actuality, salt-sensitive plants may be affected by conductivities less than 4 dS/m and salt tolerant species may not be impacted by concentrations of up to twice this maximum agricultural tolerance limit. Thus, the reclamation scientist must exercise care in interpretation of salinity standards. Salinity should be defined in terms of the predisturbance land use potential, the proposed post disturbance land use, and the plant species to be seeded on the site [84]. According to EC values and total salt percentage, classification of soils is given in Table 3.3 [15].

Table 3.3. EC values, total salt content and classification of soils

Total Salt (%)	EC (dS/m)	Salinity
0.00-0.15	0.0–4.0	Not salty
0.16-0.35	4.1–8.0	Slightly salty
0.36-0.65	8.1-15.0	Moderately salty
>65	>15.0	Strongly salty

For Güneşköy soil samples, salinity classification is obtained as given in Table 3.4 (Section 2.1.6).

Table 3.4. Salinity classification of the soil samples

Güneşköy Soils	EC (dS/m)	Total salt (%)	Salinity
1	1.349	0.050	Not salty
2	1.346	0.045	Not salty
3	1.644	0.052	Not salty
4	1.610	0.063	Not salty
5	1.037	0.033	Not salty
6	1.340	0.052	Not salty

Total salt percentage of the soil samples are between 0.033 – 0.063, all of them are smaller than 0.15 %. All of the samples have low salinity. So, in terms of salinity, all of the soils are available for good production of many plants. Distribution of % total salt of soils in Central Anatolia region (Ankara and Kırıkkale) is reported as: 95.6 % not salty, 3.8 % slightly salty, 0.4 % moderately salty, and 0.2 % strongly salty [85]. That is the soils of Central Anatolia region are available for the crop production in terms of salinity.

3.1.4. Acidity of Soils

Soil testing is the way to find out if the pH level of soil is below the optimum range for the crop production. Low soil pH increases the available aluminum content in the soil, which can be toxic to plant roots. Low pH also increases the availability of manganese, which is a required nutrient, but it is toxic if excessive amounts are present. Low soil pH reduces the efficiency by which plants take up nutrients and can also bind nutrients into forms that are not available. For plant uptake of the nutrients, pH should be the increased to a level suitable for the crop. Lime can be applied at any time of the year to change pH. Changing the soil pH requires a chemical reaction that does not occur immediately. Therefore, lime should be applied as soon as possible after the need is realized [86].

Soil pH readings in pH meter between 1 and 6 are considered acidic, 7 is neutral, and 8-14 are basic. Acidity (pH) classification of soil is given in Table 3.5 [10].

Table 3.5. Classification of soils with respect to soil pH

Strongly acidic	Moderately acidic	Slightly acidic	Neutral	Slightly Alkaline	Strongly alkaline
pH <4.5	4.5-5.5	5.6-6.5	6.6-7.5	7.6-8.5	>8.5

For the soil samples from Güneşköy, pH values are given in Table 3.6.

Table 3.6. Soil pH of samples

Güneşköy soils	pH	Acidity
1	8.15	Slightly Alkaline
2	7.86	Slightly Alkaline
3	7.89	Slightly Alkaline
4	7.96	Slightly Alkaline
5	7.87	Slightly Alkaline
6	7.96	Slightly Alkaline

pH values of the soil samples are between 7.86 – 8.15. Therefore, the soil samples from Güneşköy are slightly alkaline. In this pH, plants take up nutrients and can also bind nutrients into forms that are available. It is known that the 85.4 % of soils of Central Anatolia region are slightly alkaline [85].

3.1.5. Lime Content of Soil Samples

Lime ($CaCO_3$) is reported as percent free lime. In the routine test, values are reported as low (0 to 1 %), calcareous (1 to 5 %), and high (above 15 %). Specific values are determined and reported only when a sodium evaluation is requested on a sample. The percent free lime content is important in determining whether elemental sulfur will be an effective amendment in sodium reclamation. The lime content has no direct bearing on soil test interpretations for fertilizer recommendations [87].The levels of % $CaCO_3$ in the soil samples and classification of soil was evaluated using the criteria given in the Table 3.7. [15,88].

Table 3.7. $CaCO_3$ levels of soils

	Slightly Calcareous	**Calcar.**	**Moderately Calcareous**	**Strongly Calcar.**	**Extremely Calcar.**
% $CaCO_3$	0.0-1.0	1.1-5.0	5.1-15	15.1-25.0	>25

The % $CaCO_3$ of the soil samples collected from Güneşköy is given in Table 3.8.

Table 3.8. % $CaCO_3$ of the soil samples

Güneşköy soils	**Calcimeter readings**	**Pressure (mm/Hg)**	**Temp. (°C)**	**$CaCO_3$ (%)**	**Lime Level**
1	5.0	697	20	1.85	Calcareous
2	7.2	697	20	2.67	Calcareous
3	4.4	697	20	1.63	Calcareous
4	5.8	697	20	2.15	Calcareous
5	3.4	697	20	1.26	Calcareous
6	2.8	697	20	1.04	Calcareous

Lime content of the soil samples from Güneşköy are between 1.04 - 2.67 %. The soils are calcareous in accordance with the regional values. So ammonium sulfate as a fertilizer may be given to the soils because of their feature. However, they are not strongly calcareous for the crop production. Distribution of lime content of soils in Central Anatolia Region (Ankara and Kırıkkale) is: 6.4 % slightly calcareous, 14.9 % calcareous, 42.7 % moderately calcareous, 2.6 % strongly calcareous and 21.9 % extremely calcareous [85].

3.1.6. Concentration of Organic Matter in Soils

Organic matter contributes to improved soil physical properties (e.g. tilth, aggregation, moisture holding capacity and resistance to erosion), increasing soil organic matter will generally result in increased soil productivity. But on many soils, suitable soil physical properties occur at relatively low levels of organic matter (2-4 %). A level of organic matter higher than required to produce suitable physical properties is beneficial in that the soil has a greater buffering and nutrient holding capacity, but it does not contribute directly to soil productivity. If soils are managed, such that organic matter is not declining (steady state), soils higher in organic matter (e.g. 8 %) are not inherently more productive or fertile than those that have less organic matter (e.g. 5 %) [89].

The calculation of % organic matter in the soil samples are given in Section 2.1.8 and classification of soil samples was evaluated from the Table 3.9 [15,88].

Table 3.9. Levels of organic matter in soil

	Too low	**Low**	**Medium**	**Good**	**High**
% Organic Matter	0.0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	>4

The organic carbon and organic matter % of the soil samples collected from Güneşköy are given in Table 3.10.

Table 3.10. % Organic matter of soil samples

Güneşköy soils	Organic Carbon (%)	Organic Matter (%)	Organic matter Level
1	0.53	0.92	Too low
2	0.48	0.83	Too low
3	0.64	1.10	Low
4	1.06	1.82	Low
5	0.73	1.26	Low
6	1.19	2.04	Medium

The other important factor affecting soil quality is organic matter content. The organic matter concentrations of two samples are below 1 %, three samples have low and only one has medium organic matter content. It means the soils are limited in their organic matter content for the crop production. In that case addition of manure or ammonium sulfate and ammonium nitrate fertilizers can be considered to the soils. Distribution of organic matter concentration of soils in Central Anatolia region is: 29.1 % too little, 51.3 % little, 16.4 % medium, 2.6 % good and 21.9 % high [85].

3.1.7. Concentration of Nitrogen in Soils

Plant responds quickly to increased availability of nitrogen, their leaves turning deep in color. Nitrogen increases the plumpness of cereal grains, the protein content of both seeds and foliage, the succulence of such crops as lettuce and radishes. Nitrogen can dramatically stimulate plant productivity, whether measured in tons of grain, volume of lumber, carrying capacity of posterior thickness of lawn. Healthy plants foliage generally contains 2.5 to 4.0 % nitrogen, depending on the age of the leaves and whether the plant is legume [21].

A plant deficient in nitrogen tends to exhibit chlorosis, stunted appearance, and thin, spindly stems. In nitrogen deficient plants, the protein content is low and sugar content is high because sugar content normally destined to build proteins cannot be used to do so without sufficient nitrogen [21].

On the other hand, some plants may grow so rapidly when supplied with excessive nitrogen that they develop protoplasm faster than they can build sufficient supporting material in cell walls. Such plants are often rather weak and may be prone to mechanical injury. Development of weak straw and lodging of small grains is an example of such an effect [18].

Classification of soil samples was evaluated using the Table 3.11 [15,88].

Table 3.11. Nitrogen levels of soils

	Very low	**Low**	**Medium**	**High**	**Too High**
% N	<0.045	0.045-0.09	0.10-0.17	0.18-0.32	>0.32

Percent nitrogen of the soil samples collected from Güneşköy is given in Table 3.12.

Table 3.12. % Nitrogen concentration of soil samples

Güneşköy soils	**Nitrogen %**	**Nitrogen Level**
1	0.10	Medium
2	0.07	Low
3	0.09	Low
4	0.11	Medium
5	0.08	Low
6	0.11	Medium

The nitrogen concentration of soil samples 1, 4 and 6 is efficient for good crop production. However, nitrogen concentration of soil samples 2, 3 and 5 is not efficient; the green manure or nitrogen fertilizer must be added to the soils.

3.1.8. Concentration of Potassium in Soils

Ammonium acetate extractable potassium concentration may range from 200 mg/L to 500 mg/L, while the high potassium soils contain 1000 mg/L to over 7000 mg/L. Initial observation of crops grown on these soils continually showed poor crop yield, general chlorosis (a symptom that is commonly associated with many virus diseases. The whole leaf of a virus-infected plant may become chlorotic due to decreased chlorophyll production and the breakdown of chloroplasts) and failure to respond to fertilizer additions.

Plant production is severely reduced in excess K soils. Growth is stunted and plant density may be very low at the highest extractable K levels. Grasses often have interveinal chlorosis (a yellowing of the leaves between the veins with the veins remaining green) though general chlorosis and bright yellow vegetation are observed. Classification of soil samples was evaluated from the Table 3.13 [15,90].

Table 3.13. K_2O level of soil in kg/da

	Very low	**Low**	**Efficient**
K_2O kg/da	< 20	20-30	> 30

The potassium determinations were practiced by ammonium oxalate extraction method (Section 2.1.10). The potassium concentrations of the soil samples collected from Güneşköy determined are given in Table 3.14.

Table 3.14. Potassium concentrations of soil samples

Güneşköy soils	K_2O kg/da	Potassium Level
1	189	Efficient
2	129	Efficient
3	141	Efficient
4	301	Efficient
5	181	Efficient
6	286	Efficient

The potassium levels of analyzed soil samples are efficient for the crop production. So there is no need for addition of potassium fertilizer. Distribution of soils with respect to potassium content in Central Anatolia Region (Ankara and Kırıkkale) was reported as: 0.6 % too low, 1.25 % low and 98.15 % efficient in potassium. That means the soils of Central Anatolia region have sufficient concentration of potassium for the good crop production [85].

3.1.9. Concentration of Phosphorus in Soils

Compared to other macronutrients, such as sulfur and calcium, the concentration of phosphorus in the soil is very low, generally ranging from 0.001 mg/L in very infertile soils to 1 mg/L in rich, heavily fertilized soils. Plant roots absorb phosphorus dissolved in the soil solution, mainly as HPO_4^{2-} and $H_2PO_4^-$ ions, but some soluble organic phosphorus compounds are also taken up [21]. Calculation of phosphorus concentrations in the soil samples are given in Section 2.1.11 and classification of soil samples was evaluated from the Table 3.15 [15,88].

Table 3.15. Classification of soil samples with respect to P_2O_5 concentration

	Very low	Low	Medium	High	Too High
P_2O_5 kg/ da	< 3	3.0-6.0	6.1-9.0	9.1-12	>12

The phosphorus concentrations of the samples collected from Güneşköy are given in Table 3.16.

Table 3.16. Phosphorus concentrations of soil samples

Güneşköy soils	P_2O_5 kg/da	Phosphorus level
1	9.43	High
2	4.95	Low
3	6.21	Medium
4	35.45	Too High
5	13.76	Too High
6	31.21	Too High

In sample 1 the level of phosphorus is high. Therefore, there is no need for the usage of phosphorus fertilizer. The phosphorus concentration of soil samples 4, 5 and 6 are too high. But soil samples 2 low and 3 medium have phosphorus content for the crop production. So for these soils, phosphorus can be given to the soil as a fertilizer diamonium phosphate (DAP) and triple super phosphate (TSP). It is reported that distribution of phosphorus concentration of soils in Central Anatolia Region (Ankara and Kırıkkale) are: 13 % too low, 28 % low, 26.3 % medium, 10.8 % high and 21.9 % too high [85].

3.1.10. Concentration of Micronutrients

Micronutrients are required in very small quantities, their concentrations in plant tissue being one or more orders of magnitude lower than for the macronutrients. The ranges of plant tissue concentrations considered deficient, adequate, and toxic for several micronutrients are given Table 3.17. Deficiencies and toxicities of micronutrients may be related to total contents of these elements in the soil. More often, however, these problems result from the chemical forms of the elements in the soil and, particularly their solubility and availability to plants [21].

Deficiencies are due not only to low concentrations of these elements in soils but more often to their unavailability to growing plants. They are adsorbed by inorganic constituents such as Fe, Al, oxides and form of complexes with organic matter, some of which are only sparingly available to plants. Other such organic complexes, known as chelates, protect some of the micronutrient cations from inorganic adsorption and make them available for plant uptake. Toxicities of micronutrients retard both plant and animal growth. Removing these elements from soil and water, or rendering them unavailable for plant uptake, is one of the challenges facing soil and plant scientist [21].

Table 3.17. Levels of micronutrient concentrations in the soil

Nutrients mg kg^{-1}	**Very low**	**Low**	**Medium**	**High**	**Too High**
Mn	<4	4-14	15-50	51-170	>170
Zn	<0.2	0.2-0.7	0.8-2.4	2.5-8.0	>8.0
	Low	**Marginal**	**Adequate**		
Fe	<2.5	2.5-4.5	>4.5		
	Deficient	**Efficient**			
Cu	<0.2	>0.2			

The concentrations of micronutrients of the soil samples collected from Güneşköy are given in Table 3.18.

Table 3.18. The micronutrient concentrations (mg/kg) of the soil samples

Güneşköy Soils	**Fe**	**Cu**	**Zn**	**Mn**
1	3.42	1.12	1.53	13.46
2	3.17	0.89	0.46	10.77
3	4.12	0.95	0.63	14.31
4	3.65	1.01	1.41	14.80
5	3.64	0.83	0.74	14.36
6	4.35	0.94	1.30	15.94

Soil samples have iron concentration between 3.17 – 4.35 mg/kg. It means that the iron concentration of the soil samples is marginal for the crop production. The copper concentration of soil samples is efficient. The soil samples 2 and 3 have low zinc concentration and samples 1 and 2 have low manganese concentration. The low concentrations of zinc and manganese may affect the crop production and quality.

3.2. WATER ANALYSIS RESULTS AND EVALUATION

3.2.1. Water EC and Total Dissolved Solids (TDS)

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC). The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, usable plant water in the soil solution decreases dramatically as EC increases [48].

The irrigation water was categorized into four groups in relation to their EC values. These groups are shown in Table 3.19. [73].

Table 3.19. Salinity classification of irrigation water according to EC value

E C (dS/m)	Class		
< 0.250	T_1	Low-salinity	Excellent
0.250-0.750	T_2	Medium-salinity	Good
0.751-2.250	T_3	High-salinity	Permissible
>2.250	T_4	Very high-salinity	Doubtful

T_1: Low-salinity water can be used for irrigation on most crops in most soils with little likelihood that soil salinity will develop.

T_2: Medium-salinity water can be used if a moderate amount of leaching occurs.

T_3: High-salinity water cannot be used on soils with restricted drainage.

T_4: Very high-salinity water is not suitable for irrigation under ordinary conditions, but it may be used occasionally under special circumstances [91].

EC is used to estimate the concentration of TDS in water, using the following equation:

TDS (mg/L) = EC (dS/m) × 640

TDS is occasionally referred to as total dissolved salts (TDS) or total soluble salts (TSS), and are determined using above equation, EC and TDS values of water samples are given in Table 3.20.

Table 3.20. EC values and TDS (mg/L) of water samples

Sample	EC dS/m	TDS mg/L	Class
Ankara Ayaş 1	0.449	287	T_2
Ankara Ayaş 2	0.425	272	T_2
Ankara Çankaya	0.490	314	T_2
Ankara Çubuk	0.914	585	T_3
Ankara Gölbaşı 1	1.320	845	T_3
Ankara Gölbaşı 5	1.875	1200	T_3
Ankara Etimesgut	0.442	283	T_2
Ankara Haymana 1	0.384	246	T_2
Ankara Haymana 2	0.416	266	T_2
Ankara Kazan	0.832	533	T_3
Ankara Polatlı	0.620	397	T_2
Ankara Pursaklar	0.545	349	T_2
Ankara Sincan 1	1.044	668	T_3
Ankara Sincan 2	0.450	288	T_2
Ankara Şereflikoçhisar	0.541	346	T_2
Bolu Gerede	0.943	604	T_3
Bolu Merkez	0.870	557	T_3
Çorum Merkez	1.397	894	T_3
Çorum Laçin	1.345	861	T_3
Kırıkkale Güneşköy 1	1.241	794	T_3
Kırıkkale Güneşköy 2	0.474	303	T_2
Kırıkkale Güneşköy 3	0.737	472	T_2

Irrigation water contains a mixture of natural soluble salts. Salts in the soil and water for the irrigation must be controlled at a concentration below that which can affect crop production. The salinity classes of water samples collected from Ankara, Kırıkkale, Bolu and Çorum are T_2 and T_3. T_2 type of water has moderate salinity so these water can be used for the irrigation of the crops. High salinity irrigation water may affect the crop, fruit and vegetable production badly. However, usage of T_3 type of water is permissible for the irrigation. High-salinity water cannot be used on soils with restricted drainage.

3.2.2. pH Values and Alkalinity (Concentration of Carbonate and Bicarbonate Ions)

The hydrogen ion concentration of water is a measure of its acidity. A pH of 8.5 or higher is a good indication that the water is high in soluble salts. Using water with high pH may require special cropping and irrigation practices [91].

The pH values of water samples are shown in Table 3.21 for the acidity.

Table 3.21. pH values of water samples

Sample	pH	Alkalinity	Sample	pH	Alkalinity
Ankara Ayaş 1	7.25	Alkaline	Ankara Pursaklar	7.43	Alkaline
Ankara Ayaş 2	7.22	Alkaline	Ankara Sincan 1	7.30	Alkaline
Ankara Çankaya	7.42	Alkaline	Ankara Sincan 2	7.26	Alkaline
Ankara Çubuk	7.65	Alkaline	Ankara Şereflikoçhisar	7.25	Alkaline
Ankara Gölbaşı 1	7.71	Alkaline	Bolu Gerede	7.71	Alkaline
Ankara Gölbaşı 2	7.78	Alkaline	Bolu Merkez	7.68	Alkaline
Ankara Etimesgut	7.42	Alkaline	Çorum Merkez	7.18	Alkaline
Ankara Haymana 1	8.10	Alkaline	Çorum Laçin	7.24	Alkaline
Ankara Haymana 2	7.85	Alkaline	Kırıkkale Güneşköy 1	7.52	Alkaline
Ankara Kazan	7.39	Alkaline	Kırıkkale Güneşköy 2	8.07	Alkaline
Ankara Polatlı	7.31	Alkaline	Kırıkkale Güneşköy 3	8.07	Alkaline

The pH values of water samples are between 7.18 and 8.10. The pH of natural water normally falls between 4 and 9. Soils are generally highly buffered systems and the pH of the soil would not be significantly affected by the application of irrigation water within this range. Water samples having pH values greater than 8.0 would be expected to contain high carbonates and bicarbonates, which may form precipitate with calcium and may block the equipment. The usefulness of the water would depend on the relative amounts of these salts [92].

Alkalinity is defined as the combined effect of HCO_3^- and CO_3^{-2}. High alkalinity indicates that the water will tend to increase the pH of the soil or growing media, possibly to a point that is detrimental to plant growth. Low alkalinity could also be a problem in some situations. This is because many fertilizers are acid-forming and could, over time, make the soil too acidic for some plants. If the water is also somewhat acidic, the process would be accelerated [93].

Carbonates become a significant factor as the water pH increases beyond 8.0 and are a dominant factor when the pH exceeds about 10.3. The carbonate content of water is considered in conjunction with bicarbonates for several important evaluations such as alkalinity. Carbonates in water typically consist of precipitated calcium ($CaCO_3$) or magnesium carbonate ($MgCO_3$). They are the compounds as the active portions of lime and have a similar effect on soil and plant growth as lime. Generally, water that contains appreciable carbonates will have already exceeded desirable bicarbonate levels [93].

All of the water samples collected from Ankara, Kırıkkale, Çorum and Bolu have no carbonates. The bicarbonate concentrations from 22 different water samples in mg/L are given Table 3.22.

Table 3.22. Bicarbonate concentrations of Water Samples

Sample	HCO_3^- mg/L	Sample	HCO_3^- mg/L
Ankara Ayaş 1	208	Ankara Pursaklar	281
Ankara Ayaş 2	204	Ankara Sincan 1	394
Ankara Çankaya	249	Ankara Sincan 2	224
Ankara Çubuk	285	Ankara Şereflikoçhisar	188
Ankara Gölbaşı 1	384	Bolu Gerede	307
Ankara Gölbaşı 2	800	Bolu Merkez	280
Ankara Etimesgut	184	Çorum Merkez	292
Ankara Haymana 1	186	Çorum Laçin	292
Ankara Haymana 2	204	Kırıkkale Güneşköy 1	411
Ankara Kazan	400	Kırıkkale Güneşköy 2	255
Ankara Polatlı	267	Kırıkkale Güneşköy 3	463

Among the components of water alkalinity, bicarbonates are normally the most significant concern. Typically, bicarbonates become an increasing concern as the water pH increases from 7.4 to 9.3. However, bicarbonates can be found in water of lower pH. High levels of bicarbonates can be directly toxic to some plant species [93].

Most of the water samples collected from Ankara, Kırıkkale, Çorum and Bolu have high concentration of bicarbonate (204 – 800 mg/L bicarbonate). Bicarbonate levels above 200 mg/L will cause lime (calcium and magnesium carbonate) to be deposited on foliage when irrigated with overhead sprinklers. This may be undesirable for ornamental plants. Similar levels of bicarbonates may also cause lime deposits to form on roots, which can be especially damaging too many tree species. High water alkalinity can be corrected with acid injection [93].

3.2.3. Chloride Concentration

Chloride is a common ion in irrigation water. Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations (Table 3.23). Like sodium, high chloride concentrations cause more problems when applied with sprinkler irrigation. Leaf burn under sprinkler from both sodium and chloride can be reduced by night time irrigation or application on cool, cloudy days. Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces [48].

Table 3.23. Chloride classification of irrigation water [43]

Chloride mg/L	Effect on Crops
<70	Safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plants show injury
>350	Can cause severe problems

Listing of plants in order of increasing tolerance to chloride:

(Low tolerance) dry bean **<** onion **<** carrot lettuce **<** pepper **<** corn **<** potato **<** alfalfa **<** Sudan grass **<** zucchini **<** squash **<** wheat **<** sorghum **<** sugar beet **<** barley (high tolerance) [48].

In this study the chloride concentration of water samples are given in Table 3.24.

Table 3.24. Chloride ion concentration of water samples

Sample	Chloride Ion (mg/L)	Sample	Chloride Ion (mg/L)
Ankara Ayaş 1	17	Ankara Pursaklar	35
Ankara Ayaş 2	9	Ankara Sincan 1	138
Ankara Çankaya	22	Ankara Sincan 2	24
Ankara Çubuk	88	Ankara Şereflikoçhisar	41
Ankara Gölbaşı 1	118	Bolu Gerede	87
Ankara Gölbaşı 2	93	Bolu Merkez	183
Ankara Etimesgut	34	Çorum Merkez	36
Ankara Haymana 1	23	Çorum Laçin	32
Ankara Haymana 2	20	Kırıkkale Güneşköy 1	62
Ankara Kazan	39	Kırıkkale Güneşköy 2	20
Ankara Polatlı	30	Kırıkkale Güneşköy 3	36

Six water samples collected from Ankara (Sincan, Çubuk and Gölbaşı) and Bolu (Gerede for Merkez) has high concentration of chloride ion for the crop production of sensitive plants. High level of chloride concentration can cause root injury, accumulate in shoot tissues and cause shoot toxicity problems, or cause direct foliar toxicity on plant leaves.

3.2.4. Concentration of Calcium and Magnesium

The concentrations of calcium and magnesium (mg/L) in water samples and water hardness are given in Table 3.25. These values were used for determination of sodium adsorption ratio (SAR) and hardness in French or German degree of hardness. Water hardness is the overall concentration of divalent salts (calcium, magnesium, iron, etc.) but does not identify which of these elements are the sources of hardness. However, calcium and magnesium are the most common sources of water hardness. Liming increases hardness. It is calculated using the following equations.

French degree $= (Ca^{2+} + Mg^{2+})$ meq/L x 5

German degree = French degree x 2.8

Table 3.25. Concentrations of calcium and magnesium (mg/L) in water and water hardness

Sample	Calcium mg/L	Magnesium mg/L	Hardness (French)
Ankara Ayaş 1	42.8	26.5	22
Ankara Ayaş 2	50.8	20.7	21
Ankara Çankaya	58.0	20.2	23
Ankara Çubuk	12.8	68.2	32
Ankara Etimesgut	18.0	6.7	7
Ankara Gölbaşı 1	10.4	6.2	5
Ankara Gölbaşı 5	18.8	13.1	10
Ankara Haymana 1	36.0	17.6	16
Ankara Haymana 2	42.0	17.9	18
Ankara Kazan	20.4	60.1	30
Ankara Polatlı	46.0	38.0	27
Ankara Pursaklar	52.0	38.7	29
Ankara Sincan 1	25.6	11.9	11
Ankara Sincan 2	20.4	10.0	9
Ankara Şereflikoçhisar	53.6	28.9	26
Bolu Gerede	15.0	68.2	32
Bolu Merkez	17.4	61.7	30
Çorum Merkez	130	69.2	61
Çorum Laçin	123	63.9	57
Kırıkkale Güneşköy 1	97.2	93.6	63
Kırıkkale Güneşköy 2	17.6	45.7	23
Kırıkkale Güneşköy 3	27.6	80.6	41

Calcium is required for plant growth in low concentrations and is not considered toxic, but high concentrations can affect the calcium to magnesium ratio and cause scale build up. Maintaining pH below 7.2 will prevent scale formation.

Calcium carbonate (alkalinity) levels greater than 125 mg/L may cause pH to rise to unacceptable levels. As concentrations above 500 mg/L will cause severe problems and is not suitable for usage. High concentrations will cause scale build-up in irrigation systems [92].

In magnesium dominated water or magnesium soil (soil-water ratio of Ca/Mg < 1), the potential effect of sodium may be slightly increased. In other words, a given Sodium Adsorption Ratio (SAR) value will show slightly more damage if the Ca/Mg ratio is less than 1. The lower the ratio, the more damaging is the SAR.

There are insufficient data to make either the Ca/Mg ratio or the calcium to total cation ratio an evaluation factor when judging the suitability of a water for irrigation, but if an irrigation water is being used that has a Ca/Mg ratio less than one, or a calcium to total cation ratio less than 0.15, a further evaluation is needed. Although no conclusive recommendations can be made, such water may pose a potential problem related to plant nutrition and an evaluation may be needed to determine if a readily available source of soluble calcium exists in the soil or whether further studies are needed to determine if calcium should be added as a fertilizer or soil amendment [94].

3.2.5. Concentration of Potassium and Sodium, and Classification of Water According to Sodium Adsorption Ratio (SAR)

Potassium is a minor element in irrigation water; consequently, potassium determination is no longer a routine part of irrigation water analysis.

While EC is used for the assessment of all soluble salts in a sample, sodium hazard is defined separately because of sodium's specific detrimental effects on soil. The sodium hazard is typically expressed as SAR [48].

The index used is SAR that expresses the relative activity of sodium ions in the exchange reactions with the soil. This ratio measures the relative concentration of sodium to calcium and magnesium.

SAR is defined by the following equation:

$$SAR = \frac{\left[Na^{+}\right]}{\sqrt{\frac{\left[Ca^{2+}\right]+\left[Mg^{2+}\right]}{2}}}$$

where Na, Ca and Mg concentrations are expressed in meq/L.

General classifications of irrigation water based upon SAR values are presented in Table 3.26 [48].

Table 3.26. General classification of water sodium hazards based on SAR values

SAR Values	Sodium hazard of water	Class
1-9	Low	A_1
10-17	Medium	A_2
18-25	High	A_3
≥26	Very High	A_4

A_1: Low-sodium water can be used for irrigation on almost all soils with little danger of developing harmful levels of sodium.

A_2: Medium-sodium water may cause an alkalinity problem in fine-textured soils under low leaching conditions. It can be used on coarse textured soils with good permeability.

A_3: High-sodium water may produce an alkalinity problem. This water requires special soil management such as good drainage, heavy leaching, and possibly the use of chemical amendments such as gypsum.

A_4: Very high sodium water is usually unsatisfactory for irrigation purposes [91].

Sodium hazard based on SAR values of analyzed water samples are given in Table 3.27.

Table 3.27. Concentrations of K and Na, SAR values of water samples and their classifications

Sample	Potassium mg/L	Sodium mg/L	SAR Value	Class of Water
Ankara Ayaş 1	0.8	2.70	0.1	A_1
Ankara Ayaş 2	0.8	2.10	0.1	A_1
Ankara Çankaya	2.9	8.70	0.3	A_1
Ankara Çubuk	3.1	69.0	1.7	A_1
Ankara Gölbaşı 1	2.9	279	16.9	A_2
Ankara Gölbaşı 5	4.7	400	17.2	A_2
Ankara Etimesgut	3.9	66.2	3.4	A_1
Ankara Haymana 1	1.2	20.9	0.7	A_1
Ankara Haymana 2	1.6	20.9	0.7	A_1
Ankara Kazan	0.8	69.0	1.7	A_1
Ankara Polatlı	2.9	19.8	0.5	A_1
Ankara Pursaklar	3.1	19.8	0.5	A_1
Ankara Sincan 1	4.7	200	8.2	A_1
Ankara Sincan 2	1.4	59.8	2.7	A_1
Ankara Şereflikoçhisar	1.8	12.7	0.4	A_1
Bolu Gerede	3.1	69.0	1.7	A_1
Bolu Merkez	3.1	63.3	1.6	A_1
Çorum Merkez	3.5	80.5	1.4	A_1
Çorum Laçin	3.5	69.0	1.3	A_1
Kırıkkale Güneşköy 1	2.3	57.5	1.0	A_1
Kırıkkale Güneşköy 2	3.1	3.20	0.1	A_1
Kırıkkale Güneşköy 3	0.8	24.8	0.6	A_1

SAR values between 1 and 9 mean water has low concentration of sodium. This type of water (A_1) can be used for irrigation on almost all soils with little danger of developing harmful levels of sodium. Samples from Gölbaşı have SAR values around 17. The water samples collected from other regions have SAR values between 1 and 9.

3.2.6. Residual Sodium Carbonate Content of Irrigation Water

Residual sodium carbonate (RSC) is a value that indicates the sodium hazard in water due to the loss of calcium and magnesium ions from the water by their reaction with bicarbonate and carbonate ions [95]. The sodium permeability hazard for irrigation water is usually assessed when bicarbonate and carbonate levels are >1.97 and 0.50 meq/L, respectively. RSC is important because it is not the absolute bicarbonate and carbonate concentrations that are important, but instead, the relative concentrations of bicarbonate and carbonate compared to concentrations of calcium and magnesium. RSC is calculated as follows [96]:

$$\textbf{RSC (meq/L)} = ([HCO_3^-] + [CO_3^{2-}]) - ([Ca^{2+}] + [Mg^{2+}])$$

For this equation, all concentrations are expressed in meq/L. Typically; water with a RSC value lower than 1.25 meq/L is safe for irrigating turf. RSC values between 1.25 - 2.5 meq/L is marginal, and above 2.5 meq/L is considered excessive [96]. The RSC values of irrigation water are given in Table 3.28.

Table 3.28. RSC values of irrigation water [96]

RSC Hazard					
Units	**None**	**Increasing**	**Significant**	**High**	**Severe**
meq/L	< 1.24	1.25–1.7	1.8-2.1	2.2-2.5	> 2.5

If water RSC is high, extended use of that water for irrigation will lead to an accumulation of sodium in the soil. The results of this include direct toxicity to crops, excess soil salinity (EC) and associated poor plant performance, and where appreciable clay or silt is present in the soil, loss of soil structure and associated decrease in soil permeability [96].

RSC values of water samples collected from Ankara, Kırıkkale, Çorum and Bolu are given in Table 3.29.

Table 3.29. RSC values of water samples

Sample	RSC Value	Sample	RSC Value
Ankara Ayaş 1	-0.93	Ankara Pursaklar	-1.22
Ankara Ayaş 2	-0.93	Ankara Sincan 1	4.18
Ankara Çankaya	-0.50	Ankara Sincan 2	1.82
Ankara Çubuk	-1.65	Ankara Şereflikoçhisar	-2.00
Ankara Gölbaşı 1	5.25	Bolu Gerede	-1.41
Ankara Gölbaşı 2	11.1	Bolu Merkez	-1.42
Ankara Etimesgut	1.55	Çorum Merkez	-7.49
Ankara Haymana 1	-0.22	Çorum Laçin	-6.70
Ankara Haymana 2	-0.25	Kırıkkale Güneşköy 1	-5.93
Ankara Kazan	0.52	Kırıkkale Güneşköy 2	-0.51
Ankara Polatlı	-1.09	Kırıkkale Güneşköy 3	-0.50

RSC values of water samples Ankara Gölbaşı and Sincan 1 are greater than 2.50 meq/L and these water samples are not suitable for the irrigation. RSC values of Etimesgut, Sincan 2 and Kazan water samples are positive and lower than the value 2.00 meq/L. All the other water samples have negative RSC values so they are the safe for irrigation.

3.2.7. Boron Concentration

Boron is present in water as boric acid and in this form may be toxic to plants even at very low concentrations. Plant species differ in their tolerance to boron as identified in Table 3.30.

Table 3.30. Plant tolerances to boron

Sensitive	Semi -Tolerant	Tolerant
Pecan	Sunflower	Sugar beet
Black walnut	Cotton	Garden beet
Navy bean	Radish	Alfalfa
Pear	Field pea	Onion
Apple	Barley	Turnip
Peach	Wheat	Cabbage
	Corn	Lettuce
	Milo	Carrot
	Oats	
	Pumpkin	
	Sweet potato	

Classification of irrigation water in relation to its boron content and crop tolerance is shown in Table 3.31. Boron toxicity is not common in some of the cities of our country although boron is routinely analyzed in irrigation water tests [97]. Some vegetable and row crops are sensitive to boron. Generally leaf injury must be severe to cause reduced yields and crop quality. Long term use of irrigation water containing more than 0.5 mg/L boron can reduce the yields of the bean, onion, garlic, and strawberry; 0.7 mg/L boron can reduce the yields of broccoli, carrot, potato, and lettuce; and concentrations greater than 2 mg/L can reduce yields of cabbage and cauliflower [98].

Table 3.31. Classification of irrigation water based on boron concentration in relation to plant tolerance

Classification	Sensitive plants	Semi-tolerant plants	Tolerant plants
	Boron in mg/L		
Excellent	<0.3	<0.6	<1.0
Good	0.4–0.6	0.7–1.3	1.0–2.0
Fair	0.7–1.0	1.4–2.0	2.1–3.0
Poor	1.1–1.3	2.1–2.5	3.1–3.8
Unsuitable	>1.3	>2.5	>3.8

Boron concentrations and classification of water according to boron are given in Table 3.32 for the irrigation water samples.

Table 3.32. Classification of irrigation water samples with respect to boron

Sample	Boron (mg/L)	Classification
Ankara Ayaş 1	3.23	Unsuitable for sensitive and semi-tolerant plants
Ankara Ayaş 2	1.02	Good for tolerant plants
Ankara Çankaya	1.02	Good for tolerant plants
Ankara Çubuk	Not Detected	Excellent for all plants
Ankara Gölbaşı 1	Not Detected	Excellent for all plants
Ankara Gölbaşı 2	1.01	Good for tolerant plants
Ankara Etimesgut	3.23	Unsuitable for sensitive and semi-tolerant plants
Ankara Haymana 1	1.02	Good for tolerant plants
Ankara Haymana 2	1.97	Fair for sensitive and semi-tolerant plants
Ankara Kazan	Not Detected	Excellent for all plants
Ankara Polatlı	3.23	Unsuitable for sensitive and semi-tolerant plants
Ankara Pursaklar	Not Detected	Excellent for all plants
Ankara Sincan 1	Not Detected	Excellent for all plants
Ankara Sincan 2	Not Detected	Excellent for all plants
Ankara Şereflikoçhisar	1.97	Fair for sensitive and semi-tolerant plants
Bolu Gerede	Not Detected	Excellent for all plants
Bolu Merkez	Not Detected	Excellent for all plants
Çorum Merkez	1.97	Fair for sensitive and semi-tolerant plants
Çorum Laçin	Not Detected	Excellent for all plants
Kırıkkale Güneşköy 1	1.73	Fair for sensitive and semi-tolerant plants
Kırıkkale Güneşköy 2	Not Detected	Excellent for all plants
Kırıkkale Güneşköy 3	3.23	Unsuitable for sensitive and semi-tolerant plants

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In Turkey, usage of increasing amounts of nitrogen, phosphorus and potassium fertilizers and pesticides by some unconscious farmers cause soil pollution and soil infertility for the crop production. Usage of water in excessive amounts and/or in poor quality for irrigation creates problems during the plant production. Assessment of soil and water quality is very important for good crop production and preventing the soil pollution. So the quality of soil and irrigation water must be determined for producing good quality crop and increasing of crop production.

Analytical chemistry and methods of instrumental analysis are essential in soil and water analysis procedures. Soil quality is determined by chemical and physical analysis include major nutrients - nitrogen, phosphorus, and potassium, minor nutrients - iron, manganese, copper, zinc, boron, molybdenum, physical properties - soil acidity, electrical conductivity, soil organic matter, moisture content, and soil contaminants. The quality of irrigation water is determined by pH, total concentration of soluble salts assessed through EC, relative proportion of Na to other cations such as Ca and Mg, referred to as the sodium adsorption ratio (SAR), concentration of B and other elements that may be toxic to plants, concentration of carbonates and bicarbonates as related to the concentration of Ca and Mg, referred to as residual sodium carbonate (RSC), content of anions such as chloride, sulfate and nitrate.

Soil and water analyses are performed by laboratories that offer an extensive array of specific tests. There are many very well established soil and water analysis laboratories in Turkey. Laboratory tests are more accurate and frequently include professional interpretation of results and recommendations. These may outline any anomalies, exceptions and shortcomings in the sampling and/or analytical process/results. However, the access to these laboratories may be prohibitive to some of the farmers because of the distance, time and cost. Under these circumstances field analysis of soils and water might be the solution. For the development of field analysis techniques it is necessary to understand the laboratory analysis techniques. So in this study, soil and water samples were analyzed by using simple and reliable techniques for the determination of plant nutrients in soil and water in laboratories of METU and Soil Fertilizer and Water Resources Central Research Institute Laboratory in Ankara. The soil and water samples were collected using the standard techniques from Ankara, Bolu, Çorum and Kırıkkale.

Soil quality was determined by performing the following test and analyses:

- Measurement of soil pH using pH meter,
- Electrical conductivity using EC meter,
- Determination of soil texture by saturation,
- Organic matter by titration,
- Lime content using Scheibler Calcimeter,
- Analysis of primary nutrients
    - Nitrogen by Kjeldahl method,
    - Phosphorus using spectrophotometer,
    - Potassium using flame photometer
- Micronutrients (iron, copper, manganese and zinc) using ICP, by Soil Fertilizer and Water Resources Central Research Institute laboratory.

The soil analysis results were interpreted using the literature and reported in terms of the nutrients to be supplemented. These analyses may help farmers to add deficient nutrients to the soils for the correct balance to obtain high quality products, with high yield. According to the soil test results, the textures of the soil samples are found as loam and clay loam. The total salt content of the soil samples are between 0.033 – 0.063 %, meaning they are low salinity soils (salinity less than 0.15 %) suitable for crop production. The pH of the soil samples are between 7.86 and 8.15, they are slightly alkaline.

The phosphorus concentration of soil samples are in a range of 4.95-35.45 P_2O_5 kg/da. Some of the soil samples have too high phosphorus content because of excessive usage of phosphorus containing fertilizers. The potassium content of soil samples are found between 141-286 K_2O kg/da, so the soils are efficient in K for crop production. Lime content of the soil samples is between 1.04-2.67 %. It means all of the soil samples are calcareous but it is not too high for the agricultural production. Organic matter content of soil samples are found between 0.92-2.04 %. This means the soils are limited in their organic matter content for the crop production.

Irrigation is an artificial application of water to the soil and it is an important factor affecting the crop production for the producers. Irrigation water is used to assist the growth of crops in dry areas and during periods of inadequate rainfall with good economic return and no damage to the land. Plants utilize natural waters including lakes, streams, and groundwater. Water used for irrigation can vary widely in quality depending on class and quantity of soluble salts. Quality of irrigation water is considerable for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment. In this study pH and alkalinity (carbonate and bicarbonate concentration), salinity hazard, sodium hazard, calcium, magnesium, chloride and boron concentrations were determined for the suitability of water usage for irrigation in agriculture.

For irrigation waters electrical conductivity was measured with EC meter and pH with pH meter. Chloride, calcium, magnesium concentrations and alkalinity of water samples were determined by titration. In water samples sodium and potassium concentrations were determined using flame photometer and boron concentrations with UV spectrophotometer.

Analysis of 22 water samples yielded EC values between 0.384 – 1.875 dS/m. Water samples have moderate to high-salinity (if EC values between 0.205 and 2.250 dS/m), yet these can be used for the irrigation of the crops. pH values of water samples are found between 7.18-8.10, meaning that they are slightly alkaline. Bicarbonate concentrations of 19 of the water samples are greater than 200 mg/L. These waters may not be suitable for irrigation of ornamental plants. All of the water samples, except water samples from Gölbaşı, have sodium absorption ratio (SAR) values between 1 and 9. Water samples with low SAR values, except water samples from Gölbaşı, can be used for irrigation of almost all soils with little danger of developing harmful levels of sodium. The Residual Sodium Carbonate (RSC) values of water samples Ankara Gölbaşı and Sincan-1 are greater than 2.50 meq/L and these water samples are not suitable for the irrigation. RSC values of Etimesgut, Sincan-2 and Kazan water samples are positive and lower than the value 2.00 meq /L. All the other water samples have negative RSC values so they are the safe to use for irrigation.

Development of field analysis techniques for some important soil and water quality parameters is very valuable. With the knowledge and experience gained in this study, practical field analysis techniques for determination of some of the soil nutrients, elements in water may be developed in the future, so that the chemical and physical properties of soil and water could be tested easily by the farmers in the field. This will help them to get better quality produce, with high yield and results in soil and water conservation and better environmental protection.

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