Anadolu Tarım Bilimleri Dergisi
Anadolu Journal of Agricultural Sciences
http://dergipark.gov.tr/omuanajas

Araştırma/Research

Anadolu Tarım Bilim. Derg./Anadolu J Agr Sci, 36 (2021)
ISSN: 1308-8750 (Print) 1308-8769 (Online)
doi: 10.7161/omuanajas.845696

Some Physico-Chemical and Mechanical Properties and Workability of Bilecik Şeyh Edebali University Campus Soils

Zeynep Demir [a,*], Zeki Mut [b], Hanife Mut [b], Erdem Gülümser [b]

[a] *Soil, Fertilizer and Water Resources Central Research Institute, Department of Soil Science and Plant Nutrition, Ankara 06172, Turkey*
[b] *Bilecik Şeyh Edebali University, Faculty of Agriculture and Natural Sciences, Department of Field Crops, Bilecik 11230, Turkey*

*Sorumlu yazar/corresponding author: zdemir06@yahoo.com

Geliş/Received 23/12/2020 Kabul/Accepted 30/12/2020

ABSTRACT
In this study, some physico-chemical and mechanical properties and appropriate moisture levels for workability of soil series in Bilecik Şeyh Edebali University Campus area in Turkey were determined. Soil samples were taken from 0 - 20 cm depth of 20 different points in Gülümbe and Aşağıköy series. Soils in the Gülümbe were clay (C) and clay loam (CL) in texture with a mean bulk density of 1.05 g cm^{-3}, saturated hydraulic conductivity of 0.66 cm h^{-1}, slightly alkaline (pH=7.74), medium soil organic matter (SOM) (2.01%), high lime (17.08%), insufficient available phosphorus (1.92 kg P_2O_5 da^{-1}), sufficient available potassium (88.54 kg K_2O da^{-1}), cation exchange capacity (CEC) of 37.71 cmol kg^{-1}, insufficient available Fe (2.35 mg kg^{-1}) and available Mn (5.18 mg kg^{-1}), sufficient available Zn (1.81 mg kg^{-1}) and available Cu (1.00 mg kg^{-1}) contents. Soils in the Aşağıköy were loamy (L) and sand-clay-loam (SCL) in texture with a bulk density of 1.31 g cm^{-3}, saturated hydraulic conductivity of 2.32 cm h^{-1}, slightly alkaline (pH=7.74), low organic matter (1.81%), medium lime (6.75%), high available phosphorus (18.76 kg P_2O_5 da^{-1}), sufficient available potassium (133.94 kg K_2O da^{-1}), CEC of 25.26 cmol kg^{-1}, sufficient available Fe (5.67 mg kg^{-1}) and available Cu (2.57 mg kg^{-1}), insufficient available Mn (3.21 mg kg^{-1}) and available Zn (0.66 mg kg^{-1}) contents. While the highest liquid limit (LL) (68.17%) and plastic limit (PL) (31.49%) values were determined in Gülümbe series with the highest clay content and the lowest LL (46.50%) and PL (24.80%) values were in Aşağıköy series with the lowest clay content. Plasticity index (PI) of the soils in Gülümbe and Aşağıköy series respectively varied between 32.73 - 40.26% with a mean of 36.17% and between 21.70 - 28.0% with a mean of 24.73%. Based on LL and PI values, Gülümbe soils were classified as "highly plastic inorganic clays" and Aşağıköy soils were classified as "moderately plastic inorganic clays". LL values of the soils had significant correlations with clay (0.88**), sand (-0.71*), PL (0.75**), PI (0.89**), consistency index (0.57*), SOM (0.62*), CEC (0.75**) and available K_2O (0.54*). The upper and lower moisture limits for optimum tillage were recommended as 29.15 - 23.50% for Gülümbe series and as 24.95 - 21.24% for Aşağıköy series. It was concluded that campus soils could be cultivated at field capacity without any structural deformations because of the consistency index values were between 0.75 - 1.00.

Keywords:
Soil physicochemical properties
Field capacity
Atterberg limits
Consistency index
Clay activity
Soil workability

Bilecik Şeyh Edebali Üniversitesi Kampüs Topraklarının Bazı Fiziko-Kimyasal ve Mekaniksel Özellikleri ve İşlenebilirlikleri

ÖZET
Bu çalışmada, Bilecik Şeyh Edebali Üniversitesi Kampüs alanında yer alan toprak serilerinin bazı fiziko-kimyasal ve mekaniksel özellikleri ve işlenebilirlikleri için uygun nem düzeyleri belirlenmiştir. Gülümbe ve Aşağıköy toprak serilerinden 0-20 cm derinlikten 20 farklı noktadan toprak örnekleri alınmıştır. Gülümbe serisindeki topraklar killi (C) ve killi tın (CL) bünyeli, ortalama hacim ağırlığı 1.05 g cm^{-3}, doygun hidrolik iletkenlik değeri 0.66 cm h^{-1}, hafif alkalin (pH=7.74), orta düzeyde organik madde (%2.01), yüksek düzeyde kireç (%17.08), yetersiz düzeyde elverisli fosfor (1.92 kg P_2O_5 da^{-1}),

Anahtar Sözcükler:
Fiziko-kimyasal toprak özellikleri
Tarla kapasitesi
Atterberg limitleri
Kıvam indeksi

yeterli düzeyde elverişli potasyum (88.54 kg K_2O da^{-1}), katyon değişim kapasitesi 37.71 cmol kg^{-1}, yetersiz düzeyde elverişli Fe (2.35 mg kg^{-1}) ve Mn (5.18 mg kg^{-1}), yeterli düzeyde elverişli Zn (1.81 mg kg^{-1}) ve Cu (1.00 mg kg^{-1}) içermektedir. Aşağıköy serisindeki topraklar tınlı (L) ve kumlu killi tın (SCL) tekstürlü, ortalama hacim ağırlığı 1.31 g cm^{-3}, doygun hidrolik iletkenlik değeri 2.32 cm h^{-1}, hafif alkalin (pH=7.74), düşük düzeyde organik madde (1.81%), orta düzeyde kireç (6.75%), yüksek düzeyde elverişli fosfor (18.76 kg P_2O_5 da^{-1}), yeterli düzeyde elverişli potasyum (133.94 kg K_2O da^{-1}), katyon değişim kapasitesi 25.26 cmol kg^{-1}, yeterli düzeyde elverişli Fe (5.67 mg kg^{-1}) ve Cu (2.57 mg kg^{-1}), yetersiz düzeyde elverişli Mn (3.21 mg kg^{-1}) ve Zn (0.66 mg kg^{-1}) içermektedir. En yüksek likit limit (LL) (%68.17) ve plastik limit (PL) (%31.49) değerleri en yüksek kil içeriğine sahip olan Gülümbe serisinde belirlenirken, en düşük LL (%46.50) ve PL (%24.80) değerleri en düşük kil içeriğine sahip olan Aşağıköy serisinde belirlenmiştir. Gülümbe and Aşağıköy serilerinde toprakların plastiklik indeksi (PI) sırasıyla %32.73 - 40.26 arasında olup ortalama %36.17 ve %21.70 - 28.0 arasında olup ortalama %24.73'tür. LL ve PI değerlerine göre, Gülümbe serisine ait topraklar "fazla plastik inorganik killer" grubuna ve Aşağıköy serisine ait topraklar ise "orta derecede plastik inorganik killer" grubunda sınıflandırılmıştır. Toprakların LL değerleri kil (0.88**), kum (-0.71*), PL (0.75**), PI (0.89**), kıvam ideksi (0.57*), organik madde (0.62*), katyon değişim kapasitesi (0.75**), elverişli potasyum (0.54*) ile önemli korelasyonlar göstermiştir. Gülümbe ve Aşağıköy serilerindeki toprakların optimum işlenmeleri için en uygun nem düzeyinin üst ve alt sınırı sırasıyla %29.15 - 23.50 ve %24.95 - 21.24 olarak belirlenmiştir. Bilecik Şeyh Edebali Üniversitesi Kampüs alanındaki toprakların kıvam indeksi değerlerinin 0.75 ile 1.00 arasında olması nedeniyle toprak strüktüründe bozulmalara neden olmadan tarla kapasitesindeki nem düzeylerinde işlenmelerinin uygun olacağı belirlenmiştir.

Killerin aktivitesi
Toprak işlenebilirliği

1. Introduction

Soil behaviors in agricultural and engineering practices are largely dominated by physical characteristics (Phogat et al., 2015). Such physical characteristics directly influence penetration of the roots deep into soil profile, soil water holding capacity, available nutrients, soil aeration and heat diffusion. Soil other characteristics like chemical and biological characteristics are also designated by physical characteristics (Chris Sheba et al., 2019). Texture and structure are the most significant physical characteristics of the soils. While texture implies the relative proportion of each sand, silt and clay particles, structure implies the arrangement of induvial individual particles. Both parameters designate soil porosity and pore size distribution. Soil pores then directly influence soil air-water-heat relationships. Soil texture is an inherent characteristic, but structure can be altered through various processes and implementations. Soil tillage may alter soil structure, so cultural practices should be conducted at proper soil moistures to prevent possible destructions in soil structure.

Plant growth and development are largely influenced by several physicochemical and biological characteristics of the soils. Soil quality for plant growth and development is designated by soil aeration and temperature. These parameters are largely dominated by soil moisture (Phogat et al., 2015). Soil structure is assessed through various factors including porosity, infiltration rate, hydraulic conductivity, bulk density, level of compaction, soil moisture and aeration. Aggregate stability and particle size distribution, especially the quantity of macro (>250 mm) and micro (<250 mm) aggregates have significant effects on porosity, pore sizes and continuity or discontinuity of the pores (Six et al., 2004). As compared to micro aggregates, macro aggregates generally have greater organic matter and nutrient contents. Macro aggregates are less prone to soil erosion, may generate larger pores, thus offer better aeration and infiltration conditions (Niewczas and Witkowska-Walczak, 2003). Then, for better quality, soils are desired to have greater quantity of stable macro aggregates (Buczko and Bens, 2006).

Soil compaction alters aeration and infiltration conditions of the soils. Soil tillage induces soil compaction when performed at improper soil moistures. Thus, tillage should be practiced at optimum soil moisture levels. In soil mechanics, optimum water content is the water content at which the maximum dry unit weight was achieved under certain quantity of compactive effort. However, the term in soil tillage (optimum water content for tillage- OPT) is defined as the water content at which tillage produces the greatest proportion of small aggregates. Soil tillage at wetter or drier side of the optimum moisture may generate damages in soil structure and aggregate stability. In case of soil tillage at wetter side of optimum, structural damages are encountered through production of larger clods. In case of soil tillage at drier side of optimum, greater quantity of energy is needed to overcome the shear strength or friction among the soil particles. OPT is generally related to consistency limits, so called as Atterberg Limits, of the soils. Atterberg limits are a basic measure of critical soil moisture contents of fine-grained soils and include liquid limit (LL), plastic limit (PL) and shrinkage limit (SL). Soil texture (sand, silt and clay contents) and organic matter content greatly influence consistency limits of the soils (Lal and Shukla, 2004). Atterberg limits are commonly used to predict soil shear strength (Sharma and Bora, 2003), compressibility (Ball et al., 2000) and mechanical behavior (Campbell et al., 1980). LL and PL are especially used in estimation of mechanical behavior of fine-grained soils and these limits reveal significant information about soil particles, organic matter, clay mineralogy and physicochemical characteristics of the soils (Soane et al., 1972).

Workability implies the desired soil conditions for tillage. It refers to soil conditions at which tillage could be practiced without causing any structural damages. Workability largely depends on tillage methods, organic matter content, soil moisture content, soil texture and bulk density. Therefore, soil workability is directly related to consistency limits (Kezdi, 1969). Soils are considered to be workable when the tillage operations are executed without any structural damage or compaction (Rounsevell, 1993).

Soil fertility implies the ability of a soil to sustain plant growth and development. It is quite a complex quality criterion for soils and closely related to available nutrients of the soils. A fertile soil has sufficient depth for sufficient root growth, adequate water holding capacity, well natural drainage, sufficient aeration, available essential nutrients and organic matter content. Maintenance of soil fertility requires proper management of nutrient supply and availability through fertilization and soil conservation practices. Soil fertility management offers optimization of plant nutrition and ultimately serves for sustainability of agricultural practices (FAO, 2006). Preservation and sustainability of soil fertility will be possible through identification of soil physical, chemical and biological characteristics and improvement of these characteristics with physical, chemical and horticultural practices (Tümsavaş, 2002). Therefore, soil fertility and characteristics should be identified and soils then be used and managed accordingly. This study was conducted to determine physico-chemical and mechanical characteristics and workability of soil series in Bilecik Şeyh Edebali University campus.

2. Materials and Methods

Soil samples taken from 0 - 20 cm soil profile of 20 different points in Bilecik Şeyh Edebali University Campus field, Turkey constituted the soil material of the present study. Samples were brought to laboratory in placed bags. Samples were air-dried under room temperature. Air-dried samples were then passed through 4 and 2 mm sieves before the analyses. Soil particle size distribution (sand, silt and clay contents) was analyzed with the use of hydrometer test (Demiralay, 1993). A pressure plate apparatus was used to determine soil moisture at field capacity (FC) and permanent wilting point (PWP) (Hillel, 1982). Available water content (AWC) was then calculated as the difference between FC and PWP (Hillel, 1982). Soil bulk density (BD) was identified as described by Tüzüner (1990). Soil total porosity was determined with the aid of Equation 1 as described in Tüzüner (1990);

$$F = 1 - (BD/2.65) \times 100 \quad (1)$$

Where; F is total porosity, %; BD is bulk density, g cm^{-3}. A value of 2.65 g cm^{-3} is an adequate estimate of particle density for moist soils.

Structural stability index (SSI) was calculated with the aid of hydrometer data by using Equation 2 (Leo, 1963):

$$SSI = \sum b - \sum a \quad (2)$$

Where; SSI = Soil Stability Index, b = clay fraction (%) and a = silt + clay fraction (%).

A wet-sieving apparatus was used to determine aggregate stability (AS) (Kemper and Rosenau, 1986). A constant-head permeameter, generally used for fine-grained soils, was used to determine saturated hydraulic conductivity (Ks) of the samples by using Equation 3 (US Salinity Lab. Staff, 1954);

$$Ks = \frac{Q}{A\,t}\left(\frac{S}{S+H}\right) \quad (3)$$

Where; Ks is saturated hydraulic conductivity, cm h^{-1}; Q is effluent discharge from the soil column, cm^3; A is cross-sectional area of soil column, cm^2; t is time passed, hours; S is length of soil column, cm; H is water head over the soil column, cm.

Mean weight diameter was calculated with the aid of dry sieving (from 2.00, 1.00, 0.50, 0.25, 0.106 and 0.053 mm sieves) data by using Equation 4 as described in (Hillel, 1982);

$$MWD = \sum_{i=1}^{k} W(i)\,\bar{x}i \quad ....(4)$$

Where; MWD is mean weight diameter, mm; x is mean diameter of a particular size range, mm; W(i) is weight of a particular size range.

Soil consistency limits (Liquid Limit – LL, Plastic Limit – PL) were determined in accordance with Black (1965). Plasticity Index (PI) was calculated as PI = LL – PL. Equation 5 was used to calculate the consistency index (Ic) with the use of LL, water content (W) and PI (Baumgartl, 2002);

Ic = (LL - W) / PI.........................(5)

Eq. 6 (Baumgartl, 2002) was used to calculate the activity of clays (A):

A= PI / (% clay content)..............(6)

Soil pH values were measured with a pH meter and electrical conductivity (EC) values were measured with an EC-meter (Richard, 1954). Scheibler calcimeter was used to determine soil lime contents (Soil Survey Staff 2014). Modified Walkley-Black method was used to determine soil organic matter (SOM) content (Kacar, 1994). Soil available P contents were determined through extraction with 0.5 M $NaHCO_3$ (pH =8.5) (Olsen et al., 1954). Samples were extracted with NH_4OAc. (pH=7.0) to get soil available potassium contents (Jackson, 1958). Cation exchange capacity (CEC) values were determined as described by Richard (1954). Micronutrients were determined in a spectrophotomer with the use of DTPA- extraction (Kacar, 1994). Available calcium and magnesium were determined according to Jackson (1958). Correlations between the investigated parameters were tested with the use of Pearson's correlation method (SPSS 19.0, SPSS Inc., 2011).

3. Results and Discussion

3.1 Soil physical characteristics

Descriptive statistics for physical and mechanical characteristics of soil series in Bilecik Şeyh Edebali University Campus were given in Table 1. For Gülümbe soil series, clay contents varied between 34.99 - 47.38%, silt contents between 19.58 - 29.83% and sand contents between 30.04 - 40.03%. For Aşağıköy soil series, clay contents varied between 19.31 - 31.90%, silt contents between 20.50 - 46.43% and sand contents between 34.26 - 56.71%. According to Soil Survey Division Staff (1993), Gülümbe series were classified as clay (C) and clay-loam (CL) and Aşağıköy series were classified as loam (L) and sandy-clay-loam (SCL). Soil texture significantly influence water holding capacity, consistency limits, CEC and erosion susceptibility of the soils (Berry et al., 2007). In this study, clay contents had significant correlations with BD (-0.70**), AS (0.75**), LL (0.88**), PI (0.85**), SOM (0.63*) and CEC (0.87**) (Table 4).

Bulk density (BD) of the soils varied between in 0.87 - 1.19 gr cm^{-3} in Gülümbe series and between 1.20 - 1.44 gr cm^{-3} in Aşağıköy series. Bulk density is used as a well indicator of soil compaction, thus it reveals significant information about porosity, infiltration and soil moisture (USDA, 1987). Bulk density also designates soil fertility and productivity (Nyéki et al., 2017). It is largely dependent on texture, OM, soil minerals (Brady, 1990). In this study, BD had significant correlations with clay (-0.70**), sand (0.75**), FC (-0.88**), PWP (-0.97**), AS (-0.76**), total F (-0.99**), Ks (-0.69*), MWD (-0.86**) and PI (-0.67**) (Table 4). Ideal BD values for root growth were reported as <1.10 g cm^{-3} for fine-grained (clay) soils and as < 1.40 g cm^{-3} for loamy soils (Soil Qual. Staff, 1999). Gülümbe soils were clay in texture and average bulk density (1.05 g cm^{-3}) was lower than the ideal value; Aşağıköy soils were loam in texture and again average bulk density (1.31 g cm^{-3}) was also lower than the ideal value. Such values indicated that present soil series were under risk of compaction unless cultivated at proper soil moistures.

Table 1. Descriptive statistics for physical and mechanical characteristics

Parameters		Gülümbe							Aşağıköy						
		Min.	Max.	Mean	SD	Skewness	Kurtosis	CV, %	Min.	Max.	Mean	SD	Skewness	Kurtosis	CV, %
Sand, %		30.04	40.03	33.61	3.90	0.88	-0.12	11.61	34.26	56.71	44.35	7.59	0.20	0.04	17.10
Silt, %		19.58	29.83	24.68	3.93	0.10	-1.50	15.94	20.50	46.43	32.14	9.15	0.28	-0.50	28.47
Clay, %		34.99	47.38	41.72	4.88	-0.46	-1.52	11.69	19.31	31.90	23.51	4.08	1.68	3.59	17.35
BD, gr cm^{-3}		0.87	1.19	1.05	0.11	-0.53	0.72	10.55	1.20	1.44	1.31	0.09	0.65	-1.06	7.11
FC, %		27.64	31.60	29.15	1.89	0.88	-1.90	6.48	20.64	26.32	24.95	1.98	0.53	-0.57	8.56
PWP, %		14.56	19.60	16.33	1.89	1.19	0.83	11.58	8.11	11.75	9.89	1.36	-0.21	-1.01	13.71
AWC, %		11.47	14.20	12.82	0.99	-0.11	-0.67	7.73	11.54	14.57	13.27	1.03	-0.66	-0.09	7.76
AS, %		55.24	76.73	66.42	7.72	-0.33	-0.52	11.63	20.08	46.22	26.31	9.83	2.36	5.69	37.36
Total F, %		54.92	67.25	60.33	4.28	0.50	0.61	7.10	45.54	54.53	50.59	3.51	-0.68	-1.07	6.94
Ks, cm h^{-1}		0.04	1.85	0.66	0.68	1.16	1.30	104.13	1.76	2.89	2.32	0.43	0.39	-1.03	18.63
SSI, %		36.45	59.36	54.02	8.74	-2.29	5.36	16.18	14.85	31.90	19.77	6.11	1.57	2.33	30.89
Aggregate stability (fractions. mm), %	2-1	32.36	52.58	40.98	6.87	0.76	1.34	16.76	23.32	33.54	29.40	3.76	-0.65	-0.71	12.77
	1-0.50	22.06	30.15	26.89	2.97	-0.61	0.33	11.06	19.88	24.44	23.04	1.59	-1.59	2.36	6.90
	0.50-0.25	19.68	39.38	30.49	7.52	-0.05	-0.87	24.67	30.29	52.80	42.83	6.77	-0.70	2.34	15.81
	0.25-0.106	0.01	0.04	0.02	0.01	0.71	-2.05	67.83	0.01	12.60	2.77	4.90	1.77	2.45	176.96
	0.106-0.053	0.37	2.89	1.57	1.01	-0.28	-1.37	64.32	0.47	4.23	1.75	1.71	1.18	-0.88	97.68
	0.053>	0.01	0.11	0.05	0.04	0.64	-1.96	84.24	0.05	0.86	0.21	0.29	2.49	6.34	138.53
MWD, mm		0.82	1.06	0.93	0.08	0.35	-0.11	8.99	0.70	0.83	0.78	0.05	-0.49	-1.34	6.56
LL, %		61.23	68.17	65.09	3.18	-0.12	-2.86	4.88	46.50	53.00	49.68	2.41	0.19	-1.54	4.85
PL, %		27.91	31.49	28.92	1.56	1.23	-0.33	5.40	24.80	25.01	24.95	0.08	-1.36	1.38	0.31
PI, %		32.73	40.26	36.17	3.22	0.36	-2.08	8.89	21.70	28.00	24.73	2.36	0.23	-1.64	9.55
Ic (at FC)		0.89	1.11	0.95	0.09	0.08	-1.43	8.66	0.95	1.16	0.99	0.08	-0.70	-0.78	7.29
A		0.78	1.09	0.88	0.12	1.48	1.60	13.55	0.82	1.18	1.07	0.12	-1.76	3.50	11.19

BD: Bulk density, FC: Field capacity, PWP: Permanent wilting point, AWC: Available water content, AS: Aggregate stability, Total F = Total porosity, Ks: Saturated hydraulic conductivity, SSI: Structural stability index, MWD: Mean weight diameter, LL: Liquid limit, PL: Plastic limit, PI: Plasticity index, Ic: Index of consistency, A: activity of clays.

Total porosity (F) values varied between 54.92 - 67.25% in Gülümbe series and between 45.54 - 54.53% in Aşağıköy series. Phogat et al. (2015) indicated that total F values should be between 30-45% for sandy soils, between 40-55% for loamy soils and between 45-60% for clay soils. Although coarse-textured soils have larger pores, total porosity is greater in fine-textured soils. However, total porosity of fine-textured soils greatly varies since these soils often undergo wet-dry cycles, thus subjected to continuous swell-shrink and aggregation-dispersion processes. Total porosity is directly dependent on soil texture and structure, but various other factors including OM, bulk density and tillage may have indirect effects on total porosity (Phogat et al., 2015). In this study, total porosity had significant correlations with BD (-0.99**), FC (0.88**), PWP (0.97**), AS (0.76**), Ks (0.67*), MWD (0.86**) and PI (0.69*) (Table 4).

Mean weight diameters (MWD) varied between 0.82 - 1.06 mm in Gülümbe series and between 0.70 - 0.83 mm in Aşağıköy series. Mean weight diameter reveals the weight of each size group and values of > 0.25 mm are desired for reliable plant growth and development. It is a measure of aggregate stability and an index of anaerobic condition, compaction, erosion risk and surface crust (Cooper, 2011). Furthermore Garcia et al. (2018) indicated that aggregate stability had significant effects on soil productivity, erosion and degradation. In present study, MWD had significant correlations with clay (0.84**), BD (-0.86**), FC (0.67*), PWP (0.83**), AS (0.75**), total F (0.86**), Ks (0.79**), SSI (0.71**), LL (0.79**), PL (0.67**) and PI (0.74**) (Table 4).

Aggregate stability (AS) of the soils varied between 55.24 - 76.73% in Gülümbe series and between 20.08 - 46.22% in Aşağıköy series. AS is a significant quality indicator of soils and largely dependent on soil OM and microbial activity. Soil aggregation and resultant aggregate stability significantly influence soil infiltration rates, water holding capacity, aeration and availability of essential nutrients (Pirmoradian et al., 2005; Six et al., 2004). In this study, AS had significant correlations with clay content (0.75**), BD (-0.76**), PWP (0.82**), total F (0.76**), Ks (0.74**), SSI (0.64*), MWD (0.75**) and PI (0.61*) (Table 4). AS designate soil resistance to mechanical impacts like rainfall and runoff and to water erosion (Canasveras et al., 2010).

Available water content (AWC) values varied between 11.47 – 14.20% in Gülümbe series and between 11.54 – 14.57% in Aşağıköy series. AWC is an indicator of the amount of water held at field capacity that can be lost through evapotranspiration and theoretically used by plants. Soil texture, depth and potential impervious barriers have significant effects on AWC. Available water content is also highly correlated with soil bulk density, compaction and OM contents (Nyéki et al., 2017).

Saturated hydraulic conductivity (Ks) values varied between 0.04 - 1.85 cm h^{-1} in Gülümbe series and between 1.76 - 2.89 cm h^{-1} in Aşağıköy series. Ks is dominantly influenced by total porosity, pore sizes and geometry (Hillel, 1982). In other words, texture is the primary factor designating saturated hydraulic conductivity. For Ks, researchers ordered the soil textures as sandy > loamy > clay and emphasized the effects of macro pores and continuity of pores on Ks, rather than the total porosity (Bahtiyar, 1996; Ozdemir, 1998). Ks values increase with increasing quantity of macro pores (Ahuja et al., 1984). In present study, Ks had significant correlations with clay (-0.67*), sand (0.59*), silt (0.64*), BD (-0.69*), AS (0.74**), total F (0.67*) and PI (0.61*) (Table 4).

Structural stability index (SSI) values varied between 36.45 - 59.36% in Gülümbe series and between 14.85 - 31.90% in Aşağıköy series. Soil structure is commonly used as an indicator of soil quality and productivity. It also designates the soil susceptibility to erosion. Agronomic practices may either improve or destruct soil structure just based on proper timing of such practices (Hillel, 1982).

3.2. Atterberg limits, consistency index and workability of the soils

Descriptive statistics for Atterberg limits, consistency index and activity of clays of the soil series in Bilecik Şeyh Edebali University Campus were provided in Table 1. Liquid limit (LL) values varied between 61.23 – 68.17% in Gülümbe series and between and 46.50 - 53.00% in Aşağıköy series. Demiralay and Güresinli (1979) classified soils based on LL as: low plastic for LL of <30%, medium plastic for LL of between 30 – 50% and highly plastic for LL of >50%. Since LL values of Gülümbe series were greater than 50%, they were classified as highly plastic. Aşağıköy series with LL values of less than 50% were then classified as medium plastic. Previous researchers indicated that soil plasticity was designated by type of clay and clay content (Mbagwu and Abeh, 1998; Sönmez and Öztaş, 1988). Plastic limit (PL) values varied between 27.91 - 31.49% in Gülümbe series and between 24.80 - 25.01% in Aşağıköy series. Greater LL and PL values of Gülümbe series were attributed to higher clay contents. LL and PL values are largely dependent on type of clay, clay content, OM content and exchangeable cations of the soils. LL and PL values generally increase with increasing OM and clay contents (Baumgarti, 2002; Gülser and Candemir, 2004). In identification of ideal time for soil tillage, Canbolat and Öztaş (1997) reported that LL and PL had positive correlations with clay content, organic matter content and CEC and negative correlations with sand content. In this study, LL had significant correlations with clay (0.88**), sand (-0.71*), SOM (0.62*) and CEC (0.75**). PL values had significant correlations with clay (0.72**), sand (-0.63*), SOM (0.59*) and CEC (0.67**) (Table 4). Significant positive correlations were observed between LL and PL (0.75**) and LL and PI (0.89**) (Table 4). These results are in a good agreement with those of Gülser and Candemir (2006), Gülser et al. (2008), Gülser et al. (2009), Gülser et al., (2010) and Demir (2020). Based on LL and PI values, Gülümbe series were classified as “highly plastic inorganic clays” and Aşağıköy series were classified as “medium plastic inorganic clays” (Munsuz, 1985). Plasticity index (PI) is the difference between LL and P Land implies the range of moisture in which soils exhibit plastic behavior. Jumikis (1984) classified soils based on PI values as: low plastic for PI of <7, medium plastic for PI of between 7 – 17 and highly plastic for PI of >17. In present study, PI values varied between 32.73 – 40.26% in Gülümbe series and between 21.70 – 28.00% in Aşağıköy series. Atanur (1973) reported increasing LL and PL values and decreasing PI values in medium and low plastic soils, decreasing LL, increasing PL, thus decreasing PI values in highly plastic soils with increasing lime contents. In this study, lime content had significant negative correlations with PI (-0.62*). Soil tillage at high PI levels results in puddling (Mueller et al., 2003). PI values of Gülümbe series were greater than Aşağıköy series, thus risk of puddling during soil tillage is greater in Gülümbe series.

Consistency index (Ic) implies soil consistency at any moisture levels. Ic values close to 1.0 indicate plastic (Ic=1.0 at PL) and values close to 0 indicate liquid behavior (Ic=0 at LL) of the soil (Baumgarti, 2002). In present study, considering the soil moistures at field capacity, consistency index values varied between 0.89 – 1.16. Such a case indicated that both series exhibited plastic behavior at field capacity. The best soil tillage is achieved at Ic values of between 0.75 – 1.0 at which soils have a compaction resistance of greater than 100 kPa (Baumgarti, 2002). Especially in heavy-textured soils with quite a high clay content, excessive dry conditions make soil tillage difficult and increase energy inputs. On the other hand, soil tillage at Ic of below 0.75 destructs soil texture. Such a case reduces hydraulic conductivity, plant nutrient uptake and then negatively influence plant growth and microbial activity (Baumgarti, 2002). Dexter and Bird (2001) indicated optimum moisture for soil tillage as the moisture content at which the greatest number of fine aggregates was obtained and such a moisture corresponded about 90% of moisture at plastic limit. Mueller et al. (2003) reported Ic of 1.15 and 90% of PL as the maximum soil moisture content for optimum tillage of cohesive soils. In present study, soil gravimetric moisture content calculated at Ic of 0.75, 1.0 and 1.15 and 90% of plastic limit were provided in Table 2 and mean soil gravimetric moisture contents were presented in Figure 1. Petelkau (1984) indicated that the best tillage was achieved at a moisture content hold at -5 kPa matrix potential and such a potential corresponded to 50-60% in clay soils, 40-75% in loamy soils and 20-85% in sand-loam soils. Optimum soil moisture content for soil tillage was reported as between 0.75 - 1.00 of Ic (Baumgartl, 2002). It can be improper cultivation of the fine-grained soils near Ic of 0.75 (37.97%) or over the field capacity (29.15%) in Gülümbe series. It seems that soil tillage at Ic of 1.0 or plastic limit (28.92%), Ic of 1.15 (23.50%) and 0.9% of plastic limit (26.03%) were suitable in Gülümbe series. Consistency index value at field capacity was near 1.00. Thus, the lower moisture limit for suitable cultivation of the soils in Gülümbe series was recommended as 23.50% and the upper moisture limit was 29.15% or field capacity (Figure 1). The lower moisture limit for suitable cultivation of the soils in Aşağıköy series was recommended as 21.24% and the upper moisture limit was 24.95% or field capacity (Figure 1). Mean consistency index of Gülümbe and Aşağıköy series (0.95 and 0.99, respectively) varied between 0.75 - 1.0, thus soil tillage around field capacity moistures was considered to be suitable (Table 1).

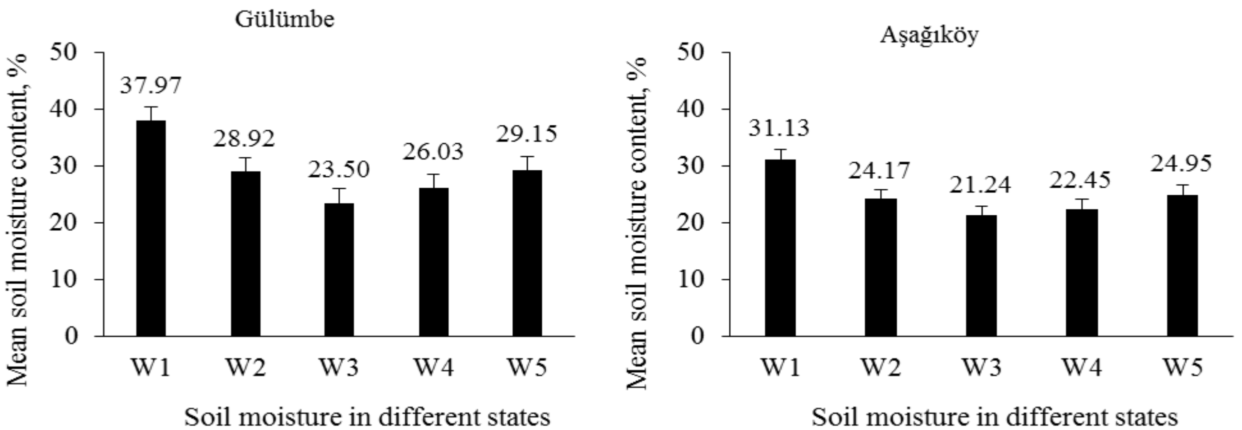

Figure 1. Soil moisture (W) at FC and different index of consistency values for suitable workability (W1 at consistency index of 0.75; W2 at consistency index of 1 or plastic limit; W3 at consistency index of 1.15; W4 at 0.9 plastic limit; W5 at FC)

Activity index (A) characterizes the relationship between the clay content and plasticity index. Skempton (1953) determined activity index values of between 1.5-7.0 for montmorillonite, between 0.5-1.2 for palygorskite, between 0.5-1.2 for illite and between 0.3-0.5 for kaolinite. In addition, Baumgartl (2002) classified soils based on A values as: active soils (smectite) for A values of >1.25; normal soils (illite) for A values of between 0.75-1.25; inactive soils (kaolinite) for A values of <0.75). In present study, A values varied between 0.78 – 1.09 in Gülümbe series and between 0.82 – 1.18 in Aşağıköy series.

Table 2. Calculated soil moisture contents for suitable workability

	Gülümbe							Aşağıköy						
	Min.	Max.	Mean	SD	Skewness	Kurtosis	CV,%	Min.	Max.	Mean	SD	Skewness	Kurtosis	CV,%
W1 (at Ic=0.75)	36.27	40.65	37.97	1.55	0.97	1.33	4.09	30.23	32.00	31.13	0.64	0.06	-1.21	2.05
W2 (at Ic=1.00 or PL)	27.91	31.49	28.92	1.56	1.23	-0.33	5.40	24.80	25.01	24.17	0.08	-1.36	1.38	0.31
W3 (at Ic= 1.15)	21.87	26.00	23.50	1.75	0.76	-1.55	7.46	20.80	21.56	21.24	0.32	-0.38	-2.11	1.49
W4 (at 0.90 PL)	25.12	28.34	26.03	1.40	1.23	-0.32	5.39	22.32	22.51	22.45	0.07	-1.39	1.50	0.31
W5 (at FC)	27.64	31.60	29.15	1.89	0.88	-1.90	6.48	20.64	26.32	24.95	1.98	0.53	-0.57	8.56

W1 at consistency index of 0.75; W2 at consistency index of 1 or plastic limit; W3 at consistency index of 1.15; W4 at 0.9 plastic limit; W5 at FC

3.3. Soil chemical characteristics

Descriptive statistics for soil chemical characteristics were provided in Table 3. Soil pH values varied between 7.50 – 7.99 in Gülümbe series and between 7.66 – 7.81 in Aşağıköy series. Present pH values revealed that soils were slightly alkaline (Ülgen and Yurtsever, 1995). Nutrient availability is largely dependent on pH. It was reported that majority of essential nutrients are available at pH values of between 5.5 – 7.0 and phosphates were not available at pH of above 7.5 (Jiao et al., 2009). In present study, soils had pH values almost at upper limit of nutrient availability.

Electrical conductivity (EC) reveals information about ion (Ca^{+2}, Na^{+1}, Mg^{+2}, K^{+1}, Cl^{-1}, SO_4^{-2}, and HCO_3^{-1}) concentration of soil extract (He et al., 2012). Electrical conductivity values varied between 0.36 - 0.63 dS m^{-1} in Gülümbe series and between 0.34 - 0.81 dS m^{-1} in Aşağıköy series. According to the classification of Richards (1954), all of the soils were classified as unsaline. There was a negative correlation between EC and pH (r = -0.54*) (Table 4). Ouhadi and Goodarzi (2007) also indicated negative relationships between soil pH and EC. The H^{+1} ions pushed out and exchange sites are occupied by salt ions, then pH values decreased with increasing salinity levels. The EC levels of between 0.2 – 1.4 are defined as reliable values for soils (Hartsock et al., 2000). Present EC values were within this range (Table 3).

Soil organic matter (SOM) contents varied between 1.45 - 2.88% in Gülümbe series and between ranged between 1.46 - 2.07% in Aşağıköy series (Table 3). According to classification of Ülgen and Yurtsever (1995), SOM content was classified as “medium” in Gülümbe series and “low” in Aşağıköy series. Six et al. (2000) and Krull et al. (2003) indicated that medium and fine-textured soils (loamy and clay) had greater organic matter contents than coarse-textured (sandy) soils. Rice (2006) indicated that clay particles sheltered organic matter and prevented decomposition of organic matter. In present study, soil organic matter content had significant correlations with clay (0.63*), CEC (0.56*), available Fe (0.72*), available Zn (0.67*), LL (0.62*) and PL (0.59*) (Table 4).

Cation exchange capacity (CEC) values varied between 31.04 - 42.99 cmol kg^{-1} in Gülümbe series and between 22.67 - 28.04 cmol kg^{-1} in Aşağıköy series (Table 3). Soil OM and clay minerals play a key role in cation exchange capacity of neutral (pH = 7) soils. Parfitt et al. (1994) indicated that dissociation of carboxyl groups increased cation exchange capacity of organic matter. CEC of organic matter was reported as between 100 to 1000 cmol kg^{-1} (Oades, 1989). On the other hand, CEC of clay minerals was reported as between 0 (pure kaolinite) and 110 cmol kg^{-1} (smectite) (Dixon and Weed, 1989). In present study, CEC had significant correlations with clay content (0.87**), SOM (0.56*), available Ca (0.74**), available P_2O_5 (0.61*), available Cu (0.52**) and available Fe (0.68*) (Table 4).

Table 3. Descriptive statistics for chemical properties of the soils

Parameters	Gülümbe							Aşağıköy						
	Min.	Max.	Mean	SD	Skewness	Kurtosis	CV,%	Min.	Max.	Mean	SD	Skewness	Kurtosis	CV,%
pH	7.50	7.99	7.74	0.16	0.14	2.22	2.02	7.66	7.81	7.74	0.07	-0.37	-2.22	0.87
EC, dS m^{-1}	0.36	0.63	0.54	0.10	-1.20	1.36	18.64	0.34	0.81	0.60	0.14	-0.54	1.80	23.97
$CaCO_3$, %	10.49	22.57	17.08	4.69	-0.42	-1.31	27.48	4.70	8.83	6.75	1.63	0.17	-1.93	24.14
SOM, %	1.45	2.88	2.01	0.63	0.65	-1.87	31.33	1.46	2.07	1.81	0.23	-0.68	-1.05	12.81
CEC, cmol kg^{-1}	31.04	42.99	37.71	3.87	-0.76	2.34	10.27	22.67	28.04	25.26	1.96	0.53	-0.75	7.76
Available P_2O_5, kg da^{-1}	0.31	3.76	1.92	1.33	0.29	-1.56	69.64	11.26	28.04	18.76	6.54	0.41	-1.90	34.87
Available K_2O, kg da^{-1}	56.20	122.86	88.54	25.17	0.09	-1.21	28.42	33.41	203.19	133.94	67.74	-0.65	-1.26	50.58
Available Ca, mg kg^{-1}	5855.00	5905.00	5867.90	19.00	2.01	4.23	0.32	4654.00	5950.00	5108.00	456.25	1.12	0.93	8.93
Available Mg, mg kg^{-1}	274.73	645.75	462.59	132.23	0.09	-0.38	28.59	365.18	760.00	495.13	126.03	1.84	4.31	25.45
Available Cu, mg kg^{-1}	0.59	1.35	1.00	0.32	-0.48	-1.92	31.67	1.85	3.36	2.57	0.59	0.23	-1.59	23.09
Available Fe, mg kg^{-1}	1.60	3.01	2.35	0.51	-0.08	-0.48	21.76	4.11	7.59	5.67	1.43	0.45	-1.76	25.12
Available Mn, mg kg^{-1}	2.37	10.40	5.18	3.48	1.01	-1.33	67.18	2.27	5.25	3.21	1.20	1.21	-0.35	37.46
Available Zn, mg kg^{-1}	0.16	5.02	1.81	1.73	1.54	2.90	95.55	0.48	0.82	0.66	0.13	-0.30	-1.46	18.98

pH: Soil reaction, EC: Electrical conductivity, SOM: Soil organic matter, CEC: Cation exchange capacity

Available phosphorus (P_2O_5) contents varied between 0.31 - 3.76 kg da^{-1} in Gülümbe series and between 11.26 - 28.04 kg da^{-1} in Aşağıköy series (Table 3). Ülgen and Yurtsever (1995) classified the available phosphorus content of soils as: deficient for < 3 kg da^{-1}, marginal for 3-6 kg da^{-1}, sufficient for 6-9 kg da^{-1}, high for 9-12 kg da^{-1} and very high for > 12 kg da^{-1}. Based on this classification, available phosphorus content was identified as "insufficient" in Gülümbe series and "very high" in Aşağıköy series. Soil pH dominates phosphorus availability and the greatest bioavailability is achieved at pH of 6.5. Thus, alkaline soils generally have lower phosphorus availability. Lime content of alkaline soils also reduces phosphorus availability. In this study, available phosphorus content of the soils had significant correlations with lime content (-0.74**) (Table 4).

Lime contents varied between 10.49 - 22.57% in Gülümbe series and between 4.70 - 8.83% in Aşağıköy series (Table 3). According to classification of Ülgen and Yurtsever (1995), lime contents were classified as "high" in Gülümbe series and "medium" in Aşağıköy series. Available potassium (K_2O) contents varied between 56.20 - 122.86 kg da^{-1} in Gülümbe series and between 33.41 - 203.19 kg da^{-1} in Aşağıköy series (Table 3). Lindsay and Norwell (1969) classified the available potassium content of soils as: deficient for < 20 kg da^{-1}, marginal for 20-30 kg da^{-1} and sufficient for > 30 kg da^{-1}. Present findings revealed that soils in the fields of Bilecik Şeyh Edebali University Campus were sufficient in potassium.

The mean values of available Fe, Cu, Mn, and Zn contents were respectively determined as 2.35, 1.00, 5.18, 1.81 mg kg^{-1} in Gülümbe series and as 5.67, 2.57, 3.21, 0.66 mg kg^{-1} in Aşağıköy series (Table 3). When classified according to the limit values specified in Sillanpää (1990), Gülümbe soils were classified as sufficient in available Cu and Zn and insufficient in available Fe and Mn. Aşağıköy soils were found to be sufficient in available Fe and Cu and insufficient in available Mn and Zn. High phosphorus contents resulted in zinc deficiency in Aşağıköy series since zinc and phosphorus have antagonistic relationships (Salimpour et al., 2010). In the present study, available Zn content of the soils had significant correlations with P (0.63*), SOM (0.67*) and Mn (0.61*). Availability of trace elements is largely dominated by soil pH (Förstner, 1995). Precipitation - dissolution reactions also play a great role in availability of these elements (Rieuwerts et al., 1998). The pH-induced charges alter bioavailability of micronutrients (Gillman, 2007). Availability of trace elements is influenced by organic carbon content dominantly controlled by soil pH (Bradl, 2004). Kabata-Pendias (2011) reported decreasing trace element concentrations with increasing soil pH levels. Available Fe content was reported to have significant positive correlations with clay content and organic matter content (Sangamner et al., 2012). In this study, available Fe contents of soils had significant correlations with pH (-0.61*), clay content (0.79**), SOM (0.72*), available Mn (0.65*), available Zn (0.73*) and $CaCO_3$ (-0.42*) (Table 4). Present findings well comply with the results of Sharma et al. (2003) and Eissa et al. (2010).

Table 4. Correlation matrix among the soil parameters

	S	Si	C	BD	FC	PWP	AWC	AS	Total F	Ks	SSI	Aggregate stability (fractions, mm)						MWD
												2-1	1-0.5	0.5-0.25	0.25-0.106	0.106-0.053	0.053>	
Si	-.31																	
C	-.50	-.67*																
BD	.75**	.14	-.70**															
FC	-.56*	-.12	.54	-.88**														
PWP	-.72**	-.22	.76**	-.97**	.87**													
AWC	.32	.20	-.43	.19	.24	-.27												
AS	-.58*	-.33	.75**	-.76**	.50	.82**	.63*											
Total F	-.75**	-.14	.70**	-.99**	.88**	.97**	-.19	.76**										
Ks	.59*	.64*	-.67*	-.69*	.53	.42	.39	.74**	.67*									
SSI	-.61*	-.40	.75**	-.48	.82**	.34	-.26	.64**	.48	.85**								
2-1	-.72**	-.28	.81**	-.82**	.64*	.80**	-.33	.75**	.82**	.76**	.79**							
1-0.5	-.56*	-.33	.74**	-.65*	.40	.68*	.56*	.72**	.65*	.68*	.64*	.63*						
0.5-0.25	.57*	.26	-.68	.58*	-.34	-.63*	.57*	-.83**	-.58*	.62*	-.64*	-.84**	-.72**					
0.25-0.106	.42	.14	-.45	.62*	-.66*	-.54	-.22	-.11	-.62*	.48	-.51	-.39	-.22	-.13				
0.106-0.053	.25	.16	-.34	.43	-.37	-.29	-.16	.07	-.43	.28	-.19	-.31	-.29	-.12	.78**			
0.053>	.43	.14	-.46	.55	-.35	-.42	.22	-.33	-.55	.36	-.31	-.56	-.25	.23	.49	.66*		
MWD	-.73**	-.30	.84**	-.86**	.67*	.83**	-.16	.75**	.86**	.79**	.71**	.99**	.70**	-.81**	-.46	-.39	-.58*	
LL	-.71*	-.44	.88**	-.65*	.54	.51	.54	.69*	.71*	.59*	.57*	.77**	.72**	-.62	-.35	-.06	-.33	.79**
PL	-.63*	-.20	.72**	-.62*	.57*	.65*	.18	.56*	.63*	.46	.76*	.76**	.65*	-.67*	-.40	-.11	-.23	.67**
PI	-.45	-.49	.85**	-.67*	.43	.61*	.63*	.61*	.69*	.61*	.62*	.73**	.69**	-.70**	-.31	-.03	-.34	.74**
Ic	-.09	.02	.05	-.26	-.48	-.20	-.55	.25	-.26	-.12	-.12	.01	.27	-.40	.57*	.51	.28	.02
A	-.04	.42	-.36	.18	-.32	-.13	-.38	.19	-.18	.31	-.16	-.24	-.07	-.07	.47	.41	.39	-.28
pH	.16	-.59*	.41	.13	-.19	-.09	-.19	-.02	-.13	-.28	-.05	.13	.31	-.19	.07	-.29	-.30	.15
EC	.23	.09	-.31	.21	.01	-.21	.44	-.45	-.21	.16	-.14	-.46	-.51	.71**	-.38	-.08	.33	-.44
$CaCO_3$	-.55	-.52	.70**	-.69*	.61*	.74**	-.27	.63*	.69*	.53	.58*	.82**	.50	-.64*	-.44	-.18	-.40	.71**
SOM	-.13	.25	.63*	-.27	.48	.36	.22	.28	.27	.11	.33	-.07	-.08	-.03	.11	.42	.23	-.09
CEC	-.67*	-.38	.87**	-.90**	.80**	.95**	-.31	.85**	.90**	.84**	.67*	.83**	.72**	-.70**	-.48	-.25	-.41	.86**
Av. P_2O_5	.46	.45	.56	.64*	.46	.42	.51	.42	.64*	.76**	.51	.67*	.71**	.78**	.08	-.15	.21	.67*
Av. K_2O	.37	-.08	-.22	.31	-.04	-.27	.46	.56*	.31	.17	.26	.40	.47	.57*	-.18	-.10	.27	.39
Av. Ca	-.49	-.30	.65*	-.71**	.58*	.68*	.19	.66*	.71**	.74**	.72**	.56*	.57*	-.37	-.58*	-.33	-.40	.61*
Av. Mg	.11	-.08	-.01	.01	.20	-.08	.55	-.26	-.01	.01	.02	-.04	-.16	.27	-.33	-.37	-.18	-.01
Av. Cu	.44	.31	.78**	.65*	.47	.44	.54	.50	.55	.61*	.51	.62*	.60*	.69**	.26	.02	.38	.72**
Av. Fe	.45	.24	.79**	.90**	-.78**	-.91**	.27	-.69**	-.90**	.77**	-.87**	-.82**	-.52	.50	.70**	.42	.59*	-.84**
Av. Mn	-.20	.22	-.05	-.28	.11	.33	-.43	.49	.28	.03	.22	-.02	.22	-.17	.14	.42	.10	-.02
Av. Zn	-.53	.37	.07	-.66*	.65*	.53	.03	.55	.66*	-.11	.53	.40	.19	-.36	-.15	.17	-.08	.39

**Correlation is significant at 0.01 level, *Correlation is significant at 0.05 level. S: Sand, Si: Silt, C: Clay, BD: Bulk density, FC: Field capacity, PWP: Permanent wilting point, AWC: Available water content, AS: Aggregate stability, Total F: Total porosity, Ks: Saturated hydraulic conductivity, SSI: Structural stability index, MWD: Mean weight diameter, LL: Liquid limit, PL: Plastic limit, PI: Plasticity index, Ic: Index of consistency, A: Activity of clays, pH: Soil reaction, EC: Electrical conductivity, SOM: Soil organic matter, CEC: Cation exchange capacity.

Table 4. Correlation matrix among the soil parameters (Continued)

	LL	PL	PI	Ic	A	PH	EC	$CaCO_3$	SOM	CEC	Av. P_2O_5	Av. K_2O	Av. Ca	Av. Mg	Av. Cu	Av. Fe	Av. Mn
Si																	
C																	
BD																	
FC																	
PWP																	
AWC																	
AS																	
Total F																	
Ks																	
SSI																	
2-1																	
1-0.5																	
0.5-0.25																	
0.25-0.106																	
0.106-0.053																	
0.053>																	
MWD																	
LL																	
PL	.75**																
PI	.89**	.75**															
Ic	.57*	-.21	-.69*														
A	.19	-.02	.37	.05													
pH	.07	.17	-.03	.47	-.59*												
EC	-.20	-.26	-.12	-.42	.35	-.54*											
$CaCO_3$	-.16	.54*	-.62*	.40	-.39	.20	-.21										
SOM	.62*	.59*	.31	-.42	.21	-.82**	.39	-.19									
CEC	.75**	.67**	.69**	.14	-.46	.12	-.33	.77**	.56*								
Av. P_2O_5	.38	.42	.31	.18	-.44	-.11	.46	-.74**	.06	.61*							
Av. K_2O	.54*	.59*	.65*	-.15	.46	-.08	.73**	-.22	.13	.37	.59*						
Av. Ca	-.41	-.47	-.32	-.42	.33	.01	-.11	.70**	.11	.74**	.71*	.46					
Av. Mg	-.26	-.31	-.20	-.50	.51	.23	-.01	.11	.16	.07	.08	.22	.26				
Av. Cu	-.37	-.40	-.30	-.58*	.55	-.17	.43	-.76**	.16	.52*	.51	.49	.53	-.01			
Av. Fe	-.07	-.26	.10	-.43	.12	-.61*	.11	-.42*	.72*	.68*	.48	.15	.68*	.03	.53		
Av. Mn	-.45	-.51	-.36	-.52	.48	-.51	-.01	-.09	.47	.17	.41	.27	.22	-.57*	.63*	.65*	
Av. Zn	.44	.54	.55	.15	-.34	-.42	-.01	.23	.67*	.46	.63*	.30	.37	-.17	.69*	.73*	.61*

**Correlation is significant at 0.01 level, *Correlation is significant at 0.05 level. S: Sand, Si: Silt, C: Clay, BD: Bulk density, FC: Field capacity, PWP: Permanent wilting point, AWC: Available water content, AS: Aggregate stability, Total F: Total porosity, Ks: Saturated hydraulic conductivity, SSI: Structural stability index, MWD: Mean weight diameter, LL: Liquid limit, PL: Plastic limit, PI: Plasticity index, Ic: Index of consistency, A: Activity of clays, pH: Soil reaction, EC: Electrical conductivity, SOM: Soil organic matter, CEC: Cation exchange capacity.

4. Conclusion

In this study, physico-chemical and mechanical characteristics of two soil series (Gülümbe and Aşağıköy) in Bilecik Şeyh Edebali University Campus were determined and suitable moisture contents for soil workability were assessed. Soils in Gülümbe series were clay (C) and clay loam (CL) in texture with a mean bulk density of 1.05 g cm^{-3}, saturated hydraulic conductivity of 0.66 cm h^{-1}, soils were slightly alkaline (pH=7.74), medium in soil organic matter (SOM) (2.01%), high in lime (17.08%), insufficient in available phosphorus (1.92 kg P_2O_5 da^{-1}), sufficient in available potassium (88.54 kg K_2O da^{-1}), cation exchange capacity (CEC) of 37.71 cmol kg^{-1}, insufficient in available Fe (2.35 mg kg^{-1}) and available Mn (5.18 mg kg^{-1}), sufficient in available Zn (1.81 mg kg^{-1}) and available Cu (1.00 mg kg^{-1}) contents. Soils in Aşağıköy series were loamy (L) and sandy-clay-loam (SCL) in texture with a bulk density of 1.31 g cm^{-3}, saturated hydraulic conductivity of 2.32 cm h^{-1}, soils were slightly alkaline (pH=7.74), low in organic matter (1.81%), medium in lime (6.75%), high in available phosphorus (18.76 kg P_2O_5 da^{-1}), sufficient in available potassium (133.94 kg K_2O da^{-1}), CEC of 25.26 cmol kg^{-1}, sufficient in available Fe (5.67 mg kg^{-1}) and available Cu (2.57 mg kg^{-1}), insufficient in available Mn (3.21 mg kg^{-1}) and available Zn (0.66 mg kg^{-1}) contents. Especially in Gülümbe series with the highest clay content (47.38%), soil tillage and seedbed preparation timing should be well defined. Soils should be tilled when the soil is mellow. Soils with different texture get mellow at different times. When the clay soils are tilled before such a time, destructions are encountered in physical structure. On the other hand, soil tillage at excessive moistures may create large clods. Organic matter supplementations can be made to improve soil aeration and structure. Increasing organic matter contents will also improve quantity and availability of essential nutrients. A well-balanced fertilization based on soil analysis results will improve soil fertility and prevent antagonistic effects of nutrients. Based on LL and PI values, Gülümbe series were classified as “highly plastic inorganic clays” and Aşağıköy series were classified as “medium plastic inorganic clays”. Upper and lower moisture limits for suitable cultivation were recommended as 29.15 - 23.50% for Gülümbe series and as 24.95 – 21.24% for Aşağıköy series. Since consistency index values varied between 0.75 – 1.00, it was concluded that Bilecik Şeyh Edebali University Campus soils could be cultivated at field capacity without any structural deformations.

Acknowledgments

The authors would like to thank the Soil Fertilizer and Water Resources Central Research Institute and Prof. Dr. Abdullah Baran and Çağla Temiz (PhD student) of Ankara University Agricultural Faculty for providing the facilities and working environment for this study.

References

Ahuja, L.R., Naney, J.W., Green, R.E., Nielsen, D.R., 1984. Macroporosity to characterize spatial variability of hydraulic conductivity and effects of land management. Soil Science Society of America Journal, 48: 699-702. https://doi.org/10.2136/sssaj198 4.03615995004800040001x.

Atanur, A., 1973. Kireç stabilizasyonu ve yol yapımındaki tatbikatı. Bayın. Bak. Karayolları G.M. Yayın No: 208.

Bahtiyar, M., 1996. Yerleşim Yeri Katı Atıklarının Tarımda Değerlendirmesi. Trakya`da Sanayileşme ve Çevre Sempozyumu, Çorlu, 3-6 Ocak 1996, s. 384-390.

Ball, B.C., Campbell, D.J., Hunter, E.A., 2000. Soil compactibility in relation to physical and organic properties at 156 sites in UK. Soil Tillage Research 57, 83–91.

Baumgartl, T., 2002. Atterberg Limits. Encyc. of Soil Sci. Marcel Dekker Inc. pp:89-93.

Berry, W., Ketterings, Q., Antes, S., Page, S., Russell Anelli, J., Rao, R., DeGloria, S., 2007. Soil Texture Agronomy Fact Sheet Series, Fact Sheet 29. Cornell University Cooperative Extension. Available at [Access date: 19.08.2018]: http://nmsp.cals.cornell.edu/publications/factsheets/factsheet29.pdf.

Black, C.A., 1965. Methods of soil analysis. Part 1. Physical and mineralogical properties, including statistics of measurement and sampling, Agronomy Monograph 9.1, American Society of Agronomy (ASA), Soil Science Society of America Journal, Madison, Wisconsin, USA.

Bradl, H.B., 2004. Adsorption of heavy metal ions on soils and soils constituents, Journal of Colloid and Interface Science, 277(1): 1-18.

Brady, N.C., 1990. The nature and properties of soils, Macmillan Publishing Company Incorporated.

Buczko, U., Bens, O., 2006. Assessing soil hydrophobicity and its variability through the soil profile using two different methods. Soil Sci. Soc. Am. J. 70: 718-727.

Campbell, D.J., Stafford, J.V., Blackwell, P.S., 1980. The plastic limit, as determined by the drop-cone test, in relation to the mechanical behavior of soil. Journal of Soil Science. 31(1), pp.11-24.

Canasveras, J.C., Barron, V., Del Campillo, M.C., Torrent, J., Gomez, J.A., 2010. Estimation of aggregate stability indices in Mediterranean soils by diffuse reflectance spectroscopy. Geoderma, 158: 78-84.

Canbolat, M.Y., Öztaş, T., 1997. Toprağın Kıvam Limitleri Üzerine Etki Eden Bazı Faktörler ve Kıvam Limitlerinin Tarımsal Yönden Değerlendirilmesi. Atatürk Üni. Ziraat Fak. Dergisi. 28(1): 120-129.

Chris Sheba M., Devaki, R., Uma, R.N., 2019. Case study on the soil physical parameters disparity and NPK concentrations in regions found in and around Pachapalayam, Coimbatore, Tamil Nadu. 5th International Conference on Man Machine Systems. IOP Conf. Series: Materials Science and Engineering 705:012052. IOP Publishing. doi:10.1088/1757-899X/705/1/012052.

Cooper, J., 2001. Soil structure, management and effect on nutrient availability and crop production. Organic Producers Conference, Facing Current and Future Challenges, Newcastle University.

Demir, Z., 2020. Some Physical and Mechanical Properties and Workability of Soils in a Sarayköy Research and Application Station. IV. International Eurasian Agriculture And Natural Sciences Congress, 30-31 October 2020, pp. 341-348.

Demiralay, I., 1993. Soil Physical Analysis. Atatürk University, Faculty of Agriculture Publication, Erzurum-Turkey, 143:131.

Demiralay, İ., Güresinli, Y.Z., 1979. Erzurum Ovası Topraklarının Kıvam Limitleri ve Sıkışabilirliği Üzerinde bir Araştırma. Atatürk Üni. Zir. Fak. Der. 10(1-2): 77-93.

Dexter, A.R., Bird, N.R.A. 2001. Methods for predicting the optimum and the range of soil water contents for tillage based on the water retention curve. Soil Til.Res. 57: 203-212.

Dixon, J.B., Weed, S.B., (eds) (1989). Minerals in soil environment. SSSA book series no. 1. SSSA, Madison.

Eissa, M.A., Nafady, M., Ragheb, H., Attia, K., 2010. Management of phosphorus fertigation for drip irrigated wheat under sandy calcareous soils. World Journal of Agricultural Sciences, 6(5): 510-516.

FAO, 2006. FAO Fertilizer and Plant Nutrition Bulletin-16. Plant nutrition for food security. A guide for integrated nutrient management. Viale delle Terme di Caracalla, 00100 Rome, Italy by R.N. Roy, A. Finck, G.J. Blair, H.L.S. Tandon. Soil fertility and crop production- Chapter 4. pp: 43.

Förstner, U., 1995. Land contamination by metals-global scope and magnitude of problem, in Metal Speciation and Contamination of Soil, H. E. Allen, C. P. Huang, G. W. Bailey, and A. R. Bowers, Eds., pp. 1-33, CRC Press, Inc., Boca Raton, FL, USA.

Garcia, C., Nannipieri, P., Hernandez, T., 2018. Chapter 9-The Future of Soil Carbon, in The Future of Soil Carbon: Its Conservation and Formation,Editor(s): Carlos Garcia, Paolo Nannipieri, Teresa Hernandez, Academic Press, pp. 239-267, ISBN 9780128116876, https://doi.org/10.1016/B978-0-12-811687-6.00009-2.

Garcia, C., Nannipieri, P., Hernandez, T., 2018. Chapter 9-The Future of Soil Carbon, in The Future of Soil Carbon: Its Conservation and Formation,Editor(s): Carlos Garcia, Paolo Nannipieri, Teresa Hernandez, Academic Press, Pages 239-267, ISBN 9780128116876, https://doi.org/10.1016/B978-0-12-811687-6.00009-2.

Gillman, G.P., 2007. An analytical tool for understanding the properties and behaviour of variable charge soils, Soil Research, 45(2): 83-90.

Gülser, C., Candemir, F., 2004. Changes In Atterberg Limits With Different Organic Waste Applications. Natural Resource Management for Sustainable Development,International Soil Congress, SSST, Atatürk University, Turkey.

Gülser, C., İç, S., Candemir, F., Demir, Z., 2008. Effects of rice husk application on mechanical properties and cultivation of a clay soil with and without planting. International Meeting on Soil Fertility Land Manag. & Agroclimatology, p:217-223, 29 Oct. -01 Nov., Kuşadası, Turkey.

Gülser, C., Candemir, F., 2006. Some mechanical properties and workability of Ondokuz Mayıs University Kurupelit Campus Soils. J.of Fac.of Agric. OMU, 2006, 21 (2): 213-217.

Gülser, C, Selvi, Ç., İç, S., 2009. Some Mechanical Properties and Workability of Soils in a Karadeniz Agricultural Research Institute Field. J Agricultural Machinery Sci., 5(4): 423-428.

Gülser, C, Dengiz, O., İç, S., Demir, Z., Selvi, K.Ç., 2010. Some mechanical properties and workability of Aşağı Aksu Basin soils. *In:* Proceedings of the International Soil Science Congress on Management of Natural Resources to Sustain Soil Health and Quality. R.Kizilkaya, C.Gulser, O.Dengiz (*eds*.), May 26-28, 2010. Ondokuz Mayis University, Samsun, Turkey. pp. 82-87.

Hartsock, N.J., Mueller, T.G., Thomas, G.W., Barnhisel, R.I.,Wells, K.L., Shearer, S.A., 2000. Soil electrical conductivity variability. In International conference on precision agriculture. (Vol. 5).

He, Y., DeSutter, T., Prunty, L., Hopkins, D., Jia, X., Wysocki, D., 2012. Evaluation of 1:5 soil to water extract electrical conductivity methods. Geoderma. 185: 1861217.

Hillel, D., 1982. Introduction to Soil Phyics. Academic Press Limited, p. 14-28. Oval Road, London.

Jackson, M.L., 1958. Soil Chemical Analysis, Prentice Hall of India Private Limited, New Delhi.

Jiao, Y., Xu, Z., Zhao, J., 2009. Effects of grassland conversion to cropland and forest on soil organic carbon and dissolved organic carbon in the farming-pastoral ecotone of Inner Mongolia. Acta Ecologica Sinica, 29: 150-154.

Jumikis, A.R., 1984. Soil Mechanics. Robert E. Krieger Publishing Company, Inc., Malabar, Florida.

Kabata-Pendias, A., 2011. Trace Elements in Soils and Plants, CRC Press, Boca Raton, FL, USA.

Kacar, B., 1994. Chemical Analysis of Plant and Soil-III. Soil Analysis, 705. Ankara University Faculty of Agriculture, Ankara, Turkey. No.3.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution In: Methods of Soil Analysis, 2nd Edn. Part I. (Ed.: A. Klute) ASA, Madison, WI. p. 425-442.

Kezdi, A., 1969. Handbuch der Bodenmechanik. Band 1, Bodenphysik, 259 pp., Band 3, Bodenmechanisches Versuchswesen, 1st edn. Berlin/Kiado Budapest: VEB Verlagfür Bauwesen, p. 274.

Krull, E.S., Baldock, J.A., Skjemstad, J.O., 2003. Importance of mechanisms and processes of the stabilization of soil organic matter for modelling carbon turnover. Functional Plant Biology 30, 207-222.

Lal, R., Shukla, M.K., 2004. Principles of Soil Physics. New York, NY, USA: Marcel Dekker Inc.

Leo, W.M., 1963. A rapid method for estimating structural stability of soils. Soil Science, 96:342-346.

Lindsay, W.L., Norwell, W.A., 1969. Development of DTPA Soil Test for Zinc, Iron, Manganese and Copper. Soil Sci. Soc. Amer. Proc., 33: 49-54.

Mbagwu, J.S.C., Abeh, O.G., 1998. Prediction of Engineering Properties of Tropical Soils Using Intrinsic Pedological Parameters. Soil Sci., 163(2): 93-102.

Sönmez, K., Öztaş, T. 1988. Iğdır Ovası Yüzey Topraklarının Bazı Fiziksel ve Kimyasal Özellikleri İle Mekaniksel Özellikleri Mekaniksel Özellikleri Arasındaki İlişkiler. Atatürk Üni. Ziraat Fak. Dergisi, 19(1-4): 145-153.

Mueller, L., Schindler, U., Fausey, N.R., Lal, R., 2003. Comparison of methods for estimating maximum soil water content for optimum workability. Soil Till. Res. 72: 9-20.

Munsuz, N., 1985. Toprak mekaniği ve teknolojisi. Ankara Üniversitesi, Ziraat Fak. Yayınları: 922, Ders Kitabı:260, Ankara.

Niewczas, J., Witkowska-Walczak, B., 2003. Index of soil aggregate stability as linear function value of transition matrix elements. Soil Till. Res. 70 (2): 121-130.

Nyéki, A., Milics, G., Kovács, A.J., Neményi, M., 2017. Effects of Soil Compaction on Cereal Yield. Cereal Research Communications, 45(1):1-22.

Oades, J.M. 1989. An introduction to organic matter in mineral soils. p. 89-159. In J.B. Dixon and S.B. Weed (ed.) Minerals in soil environments. 2nd ed. SSSA, Madison, WI.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular, Vol 939 (p.19). Washington D.C., United States Department of Agriculture. U.S. Government Printing Office.

Ouhadi, V.R., Goodarzi, A.R., 2007. Factors impacting the electro conductivity variatons of clayey soils. Iran. J. Sci. Technol. Trans. B: Eng. 31: 109-121.

Özdemir, N., 1998. Toprak Fiziği. Ondokuz Mayıs Üniversitesi Ziraat Fakültesi Yayınları, No: 30, Samsun.

Parfitt, R.L., Eason, C.T., Morgan, A.J., Wright, G.R., Burke, C.M., 1994. The fate of sodium monofluoroacetate (1080) in soil and water. Pages 59-66 in Seawright, A.A., Eason, C.T. editors. Proceedings of the Science Workshop on 1080, 12-14 December 1993, Christchurch, New Zealand. Royal Society of New Zealand, Wellington.

Petelkau, H., 1984. Auswirkungen von Schadverdichtungen auf Bodenigenschaften und Pflanzenertrag sowie Massnahmen zu ihrer Minderung. Grundlagen und Verfahren der rationellen Bodenbearbeitung und Erschliessung des Unterbodens fuer Pflanzen. Akademia der Landwirtschaftswissenschaften der DDR, Tagungsbericht Nr. 227: 25-34.

Phogat, V.K., Tomar, V.S., Dahiya, R., 2015. Soil physical properties. In: Rattan, R.K., Katyal, J.C., Dwivedi, B.S., Sarkar, A.K., Bhattachatyya, Tapan, Tarafdar, J.C. (Eds.), Soil Science: An Introduction. Indian Society of Soil Science, India, pp. 135-171.

Pirmoradian, N., Sepaskhah, A.R., Hajabbasi, M.A., 2005. Application of fractal theory to quantify soil aggregate stability as influenced by tillage treatments. Biosyst. Eng. 90(2): 227-234.

Rice, C.W., 2006. Organic matter and nutrient dynamics. Encyclopedia of Soil Science, 2: 1180-1183.

Richards, L.A., 1954. Diagnosis and Improvement of Saline and Alkaline Soils. United States Salinity Laboratory Staff. United States Department of Agriculture, 60:160.

Rieuwerts, J.S., Thornton, I., Farago, M.E., Ashmore, M.R., 1998. Factors influencing metal bioavailability in soils: preliminary investigations for the development of a critical loads approach for metals, Chemical Speciation & Bioavailability, 10(2): 61-75.

Rounsevell, M.D.A., 1993. A review of soil workability models and their limitations in temperate regions. Soil Manage. 9: 15-20.

Salimpour, S., Khavazi, K., Nadian, H., Besharati, H., Miransari, M., 2010 Enhancing phosphorous availability to canola (*Brassica napus* L.) using P solubilizing and sulfur oxidizing bacteria, Australian Journal of Crop Science, 4(5): 330-334.

Sangamner, N.A., Malpani Commerce, D.J., Sarda, B.N., 2012 Evaluation of soil fertility status from Sangamner area, Ahmednagar District, Maharashtra, India. RASAYAN. J. Chem, 5(3): 398-406.

Sharma, B., Bora, P. K., 2003. Plastic limit, liquid limit and undrained shear strength of soil-reappraisal. J. Geotechnical and Geoenvironmental Engineering, ASCE, 129(8): 774-777.

Sharma, R.P., Singh, M., Sharma, J.P., 2003. Correlation studies on micronutrients vis-à-vis soil properties in some soils of Nagpur district in semi- arid region of Rajashan. Journal of the Indian Society of Soil Science, 51: 522-527.

Sillanpää, M., 1990. Micronutrient assessment at country level: An international study. FAO Soils Bulletin 63. Food and Agricultural Organization of the United Nations, Rome.

Six, J., Bossuyt, H., Degryze, S., Denef, K., 2004. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 79: 7-31.

Six, J., Bossuyt, H., Degryze, S., Denef, K., 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 79: 7-31.

Six, J., Paustian, K., Elliott, E.T., Combrink, C., 2000. Soil structure and soil organic matter: I. Distribution of aggregate size classes and aggregate associated carbon. Soil Science Society of America Journal 64: 681-689.

Skempton, A.W., 1953. The colloidal activity of clays. In: Proceedings of the Third International Conference on Soil Mechanics and Foundation Engineering, pp. 57-61.

Soane, B.D., Campbell, D.J., Herkes, S.M., 1972. The characterization of one Scottish arable topsoils by agricultural and engineering methods. Journal of Soil Science, 23: 93-104.

Soil Quality Staff., 1999. Soil Quality Test Kit Guide. Agric. Res. Serv., Natural Resource Conserv. Serv., Soil Quality Inst., USDA.

Soil Survey Staff., 1993. National Soil Survey Handbook. USDA-SCS, Soil Survey Division. U.S. Gov. Print. Office, Washington, DC. Section 618.

Soil Survey Staff., 2014. Kellogg soil survey laboratory methods manual. Soil Survey Investigations Report No. 42, version 5.0. Burt R. et al. (eds). U.S. Department of Agriculture, Natural Resources Conservation Service, p. 279-281.

Tümsavaş, Z., 2003. Bursa İli Vertisol büyük toprak grubu topraklarının verimlilik durumlarının toprak analizleriyle belirlenmesi. Uludağ Üniversitesi Ziraat Fakültesi Dergisi 17(2): 9-21.

Tüzüner, A., 1990. Soil and water analysis laboratory manual. Ministry of Agriculture, Forestry and Rural Affairs, General Directorate of Rural Services, Ankara, Turkey.

US Salinity Lab. Staff., 1954. Diagnosis and improvement of saline and alkali soils. USDA Agricultural Handbook No. 60, Washington, DC: U. S. Government Printing Office.

USDA, 1987. Soil Mechanics Level I. Module 3 - USDA Textural Soil Classification. Study Guide., Stillwater, OK, USA: USDA, Soil Conservation Service.

Ülgen, N., Yurtsever, N., 1995. Türkiye Gübre ve Gübreleme Rehberi (4. Baskı). T.C. Başbakanlık Köy Hizmetleri Genel Müdürlüğü Toprak ve Gübre Araştırma Enstitüsü Müdürlüğü Yayınları, Genel Yayın No: 209, Teknik Yayınlar No: T.66, s.230, Ankara.