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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 7 (6): 905-911, 2004
ISSN 1028-8880

A Comparison of Some Physical and Chemical Soil Quality Indicators Influenced by Different Crop Species

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Abstract: The effects of six different crop species on some physical and chemical soil quality indicators of a clay soil were compared with a fallow plot. Cropping treatments increased the soil organic matter (OM) content from 2.28% for bare soil to 3.18% for the bromegrass treatment. Increases in OM content due to different cropping regimes were obtained in the following order: bare soil<crownvetch (CV)<subterranean clover (SC)<alfalfa (AL)<ryegrass (RG)<small burnet (SB)<bromegrass (BR). Increasing organic matter content caused considerable increases in soil structural stability (SSI), porosity (F), infiltration (I), total N and exch. K content and reductions in bulk density (BD), penetration resistance (PR), pH and exch. Na content over the bare soil. Bromegrass (BR) treatment compared with the other treatments showed the highest increases in OM of 39.5%, SSI of 9.68%, F of 14.84% and the largest decrease in BD of -12.41%. Alfalfa treatment over the bare soil showed the highest increases in EC of 124.60% and total N of 36.46%. All cropping treatments improved the infiltration ratio which had significant positive correlations with F (0.63**), SSI (571**), EC (0.47*), OM (0.47*) and significant negative correlations with BD (-0.63**), PR (-0.75**) and exchangeable Na (-0.53*). Some other significant correlations among the some soil quality indicators were as follows: F x PR (-0.72**), SSI x PR (-0.67**), OC x K (0.84**), pH x EC (-0.83**), OC x total N (0.78**), SSI x Na (-0.70**) and OC x PR (-0.67**). Besides organic matter content, EC and exch. Na content can also be indicators that define physical soil quality properties very well under different cropping treatments. Bromegrass and alfalfa may be integrated with a cropping system to improve soil physical and chemical properties and for sustainable soil management.

Key words: Cropping treatments, soil quality, physical, chemical indicators

INTRODUCTION

Soil degradation occurs rapidly under conventional tillage practice in the absence of a proper pasture phase. Grass and legume cover crops have been used successfully to improve soil properties in many regions[1]. Cover crops reduce sediment production from cropland by reducing the amount and the velocity of runoff and also increase soil quality by improving soil physical, chemical and biological properties[2]. The concept of soil quality has been defined as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance the quality of water and air and support human health and habitation" by Karlen *et al.*[3]. To interpret soil quality, there is a minimum data set of soil physical, chemical and biological properties such as texture, infiltration, porosity, structural stability, water holding capacity, soil organic matter, pH, electrical conductivity, extractable cations and soil respiration rate[4]. Arshed and Martin[5] reported that many soil indicators interact with each other and the value of one is influenced by one or more of the selected parameters. Changes in soil quality can be assessed by measuring appropriate soil quality indicators at different time intervals for a specific use in selected agro-ecosystem.

Soil structural degradation tends to accelerate high soil strength, poor infiltration, runoff and soil erosion problems. The effectiveness of pasture species like ryegrass in improving soil structure has been well reported in many studies[6,7]. Blanchart *et al.*[8] studied the effects of grass roots on the restoration of the properties of a degraded Vertisol. They found that the restoration of physical properties was more rapid and greater in treatments with plants than in treatments without plants. Plants also played a dominant role through rhizosphere effects and possible carbon rhizodeposition. It has been shown that legume ley or pasture add organic matter to the soil and encourage cracking and soil faunal activity. Increased organic matter can lead to improved soil aggregation and hence infiltration, if cover is maintained

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on the soil surface. In the longer term, improved infiltration can lead to increase production due to more efficient use of rainfall[9,10]. Cover and green manure crops grown as a conservation practice can improve soil quality by increasing organic matter, biological activity, structure stability, infiltration and nutrient cycling[11]. The objective of this paper was to determine the changes in some physical and chemical soil quality indicators of a clay soil under six different crop species in comparison to the fallow plots.

MATERIALS AND METHODS

The study was conducted at the Agricultural Faculty Experimental Field in Ondokuz Mayıs University, Samsun (41.3°N, 36.3°E), Turkey from October 1998 to July 2001. The average temperature and average annual precipitation during the field experiment were 14.6°C and 675.6 mm, respectively[12]. Twenty-one plots measuring 2x5 m each and placed 0.5m apart were used for the experiment. Six different cropping treatments and one unplanted fallow control were laid out in a randomized block design with three replications. After fall plowing and rototilling, the plots on Vertic Hapludolls were sown to perennial ryegrass, RG (*Lolium perenne* L.); alfalfa, AL (*Medicago sativa* L.); bromegrass, BR (*Bromus inermis* Leyss); small burnet, SB (*Sanquisorba minor* Scop.); subterranean clover, SC (*Trifolium subterraneum*) and purple crownvetch, CV (*Coronilla varia* L.) in October 1998. Crops were seeded in rows 40 cm apart.

Some physical and chemical soil quality indicators of each plot were determined on the soil samples taken from 0 to 15 cm depth at the start and at the end of the experiment. After passing air dried soil samples through a sieve with 2 mm size opening, some soil properties were determined as follows; particle size distribution by hydrometer method[13], soil reaction, pH, 1:1 (w:v) soil water suspension by pH meter, electrical conductivity ($EC_{25°C}$) in the same soil suspension by EC meter and exchangeable cations (Ca, Mg, K and Na) by ammonia acetate extraction[14]. Penetrometer resistance (PR) in 0-10 cm depth was measured for each plot with five replications using a standard cone penetrometer with a dial gauge, 30° conical probe and 12.8 mm. Organic matter (OM) and total N contents were determined by modified Walkley-Black method and the Kjeldahl method, respectively[14]. Volumetric water content (θ) at the soil sampling time and total porosity (F) were estimated after the bulk density (BD) was measured as three replicates by weighing undisturbed cylindrical soil cores (5.2 cm inner diameter; 5 cm depth) and oven-drying at 105°C for 24 h[15]. Volumetric water content was calculated from the following equation; θ=gravimetric water content (g H_2O/g soil at the sampling time) x soil bulk density (g cm^{-3}). Infiltration test in each plot was performed using the single ring infiltrometer technique[16] and infiltration ratio (I) was calculated from the second water run measurements. Soil structural stability index[17], SSI, was determined using the hydrometer method and calculated by the following equation: $SSI=\sum b-\sum a$, where a is the percentage of silt plus clay dispersed from the soil aggregate into suspension and b is the percentage of mechanical analyses of silt plus clay fractions after using the dispersal agent calgon in suspension.

The data were subjected to ANOVA tests and statistical differences among treatment means were computed by least significant differences (LSD) test using SAS package[18]. Simple correlation and regression analyses were carried out.

RESULTS AND DISCUSSION

Some physical and chemical properties of the soil taken at the start of the experiment are shown in Table 1. The results can be summarized as; the textural class of soil is clay, borderline low in organic matter, neutral in pH, non saline according to EC value[19].

Except exchangeable Ca content, all chemical indicators were significantly influenced by the different crop species ($p<0.01$). The treatments of crop species significantly decreased pH and exchangeable Na content from 6.54 and 0.38 me 100 g^{-1} for the bare soil to 6.15 and 0.15 me 100 g^{-1} for the CV treatment, respectively. Organic matter, total N, EC and exchangeable K content significantly increased from 2.2, 0.19, 0.31% mmhos cm^{-1} and 1.46 me 100 g^{-1} for the bare soil to 3.18% for the BR, 0.262% for the AL, 0.703 mmhos cm^{-1} for the AL and 1.74 me 100 g^{-1} for the SB treatments, respectively (Table 2). The different cropping treatments increased the soil OM content compared with the bare soil in the following order; bare soil<CV<SC<AL<RG<SB<BR. While the Ca content varied between 30.34 me 100 g^{-1} for the RG and 35.76 me 100 g^{-1} for the SB treatment, Mg content ranged from 8.74 me 100 g^{-1} for the AL to 11.02 me 100 g^{-1} for the SB treatment.

Cropping treatments significantly affected soil structural stability index (SSI), volumetric water content (θ), infiltration rate (I) and penetration resistance (PR) at

Table 1: Some physical and chemical properties of the soil at the start of the experiment

Sand (%)	19.24	NH_4OAc extractable,	me 100 g^{-1}
Silt (%)	24.92		
Clay (%)	55.53	Ca	35.66
$EC_{25°C}$, mmhos cm^{-1}	0.30	Mg	9.50
pH (1:1)	6.75	K	1.30
OM (%)	2.15	Na	0.20

Table 2: Effects of different crop species on chemical soil quality indicators

Crop species	pH 1:1	EC (mm h cm^{-1})	OM (%)	N (%)	Ca	Mg	K	Na
					(me 100 g^{-1})			
RG	6.30b	0.43c	2.70b	0.25a	30.34	10.38ab	1.49bc	0.23ab
AL	6.16c	0.70a	2.67b	0.26a	31.54	8.74c	1.55b	0.20b
BR	6.52a	0.36d	3.18a	0.25a	33.61	9.63bc	1.69a	0.21b
SB	6.32b	0.52b	3.12a	0.25a	35.76	11.02a	1.74a	0.24ab
SC	6.21bc	0.52b	2.51c	0.21b	34.41	10.43ab	1.49bc	0.16b
CV	6.15c	0.51b	2.35d	0.20b	33.10	9.68b	1.50bc	0.15b
Bare soil	6.54a	0.31e	2.28d	0.19b	34.91	10.16ab	1.46c	0.38a
LSD	0.13**	0.01**	0.15**	0.02**	-	0.89**	0.08**	0.15**

Table 3: Effects of different crop species on physical soil quality indicators

Crop species	SSI (%)	BD (g cm^{-3})	F (%)	θ (%)	I (cm h^{-1})	PR (MPa)
RG	60.41a	1.37ab	48.30ab	26.51a	2.18 b	2.50ab
AL	62.64a	1.31b	50.57a	26.00ab	2.92b	2.29cd
BR	63.00a	1.27b	52.00a	22.73abcd	2.89b	1.96cd
SB	61.78a	1.29b	51.19a	21.46cd	4.56a	1.89d
SC	61.84a	1.28b	51.57a	23.30abc	4.89a	1.99cd
CV	62.52a	1.30b	51.06a	22.22bcd	2.45b	2.44abc
Bare soil	57.44b	1.45a	45.28b	18.77d	0.56c	2.94a
LSD	2.75**	0.09*	4.78*	4.00**	0.86**	0.51**

*There is no significant difference between the same letters in each column statistically at 5% level
**There is no significant difference between the same letters in each column statistically at 1% level

Table 4: Percent changes in the chemical soil quality indicators over the bare soil (%)

Crop species	pH	EC	OM	N	Ca	Mg	K	Na
RG	-3.67	38.66	18.42	30.21	-13.09	2.16	2.05	-39.47
AL	-5.81	124.60	17.11	36.46	-9.65	-13.97	6.16	-47.36
BR	-0.31	15.97	39.47	33.85	-3.72	-5.21	15.75	-44.73
SB	-3.36	67.09	36.84	30.73	2.43	8.46	19.17	-36.84
SC	-5.05	67.41	10.09	11.46	-1.43	2.65	2.05	-57.89
CV	-5.96	65.18	3.07	8.85	-5.18	-4.72	2.73	-60.52

the 1% level and bulk density (BD) and porosity (F) at the 5% level (Table 3). Bulk density and penetrometer resistance were significantly higher in the bare soil compared with the soil under crop species (Table 3). The cropping treatments significantly decreased BD and PR from 1.45 g cm^{-3} and 2.94 MPa for the bare soil to 1.27 g cm^{-3} for the BR and 1.89 MPa for the SB treatment, respectively. Decreases in penetration resistance were obtained in the following order; bare soil>RG>CV>AL>SC>BR>SB. Due to cropping effects, SSI, F, θ and I significantly increased from 57.44, 45.28, 18.7% and 0.56 cm h^{-1} for the bare soil to 63.00% for the BR, 52% for the BR, 26.5% for the RG and 4.89 cm h^{-1} for the SC treatments, respectively. The increases in the porosity were found in the following order; bare soil<RG<AL<CV<SB<SC<BR treatment.

DISCUSSION

Effects of cropping treatments on soil quality indicators: Percentage changes in chemical soil quality indicators over the bare soil treatment are given in Table 4. All cropping treatments increased EC, OM, total N and K contents while decreasing pH and Na content compared with the bare soil. Soil organic matter content has been shown to be a key attribute of soil quality[5,20]. As an indicator for soil quality assessment, soil organic matter defines soil fertility, soil structure and pesticide and water retention[3-5]. It is known that cover and forage crops have a positive effect on soil organic matter content[6,7,21]. In this study, percent increases in the soil organic matter content over the bare soil varied between 3.07% for the CV and 39.47% for the BR treatment. Obi[21] reported that cover crops on degraded sandy clay loam soil improved mean organic carbon level (by 28.1%), improved mean cation exchange capacity and Ca and Mg levels over the values for the bare soils. Green manure crops improve nutrient utilization when the species have root systems that are able to extract and mobilize nutrients from deeper layers and the legumes can add nutrients to the soil by biological fixation[11]. Percent increases in the total nitrogen content over the control were between 8.85% for the CV and 36.46% for the AL treatment. Kushwaha *et al.*[22] found that residue retention on the soil surface with tillage reduction increased the values of soil organic carbon and total N. Bell *et al.*[23] found that extensive soil acidification occurred in cropped soil compared the virgin soil. In this study, the values of soil

Table 5: Percent changes in the physical soil quality indicators over the bare soil (%)

Crop species	SSI	BD	F	θ	I	PR
RG	5.17	-5.52	6.67	41.71	289.3	-14.96
AL	9.05	-9.66	11.68	39.03	421.4	-22.11
BR	9.68	-12.41	14.84	21.39	416.1	-33.33
SB	7.56	-11.03	13.05	14.97	714.3	-35.71
SC	7.66	-11.72	13.89	24.60	773.2	-32.31
CV	8.84	-10.34	12.76	18.72	337.5	-17.00

pH significantly decreased with the cropping treatment and the percent reductions in pH over the bare soil were between -0.31% for the BR and -5.96% for the CV treatment. Except K content, most cropping treatments caused the decrease in exchangeable cations compared with the bare soil. However, the percent increases in the K content values over the bare soil were found between 2.05% for the RG ˜ SC and 19.17% for the SB treatment. Decreases in the other exchangeable cations can be attributed to either these cations taken by the plants or these cations leached through soil profile due to increased infiltration. Bell *et al.*[23] reported that there was a reduction in exchangeable cations and effective cation exchange capacity and increases in infiltration rate in cropped lands compared with the virgin soil. The CV treatment showed the highest decreases in Na content (-60.52%) and pH value (-5.96%) together. Other than soil salinity, electrical conductivity measurements have been shown to be sensitive to high soluble nutrient levels of soils[24] and are useful in monitoring the mineralization of soil organic matters[25]. The highest percent change in EC values over the bare soil was obtained as 124.60% for the AL treatment while the lowest percent increase in EC values was 15.97% for the BR treatment. EC values over the bare soil were increased by the cropping treatments in the following order; bare soil<BR<RG<CV<SB<SC<AL.

All cropping treatments increased structural stability index, porosity, volumetric water content and infiltration ratio values while decreasing bulk density and penetration resistance values over the bare soil. Percent changes in physical soil quality indicators over the bare soil treatment are given in Table 5. Most studies have shown that cropping systems improve soil structure through several mechanisms such as aggregate enrichment by fine roots and associated fungal hyphae, stimulation of microbial carbohydrate production or modified soil-water relationships[6,21,26-28]. Soil structural stability increased due to cropping treatments in the following order; bare soil<RG<SB<SC<CV<AL<BR. Percent increase in SSI values varied between 5.17% for the RG and 9.68% for the BR treatment over the bare soil. All crop species caused significant increases in total porosity with decreasing the bulk density and penetration resistance. The highest percent changes were obtained in total porosity of 14.84% for the BR, bulk density of 12.41% for the BR and penetration resistance of -35.71% for the SB treatment. RG among the other species showed the lowest effects on F, BD and PR over the bare soil. Obi[21] reported that bulk density and penetrometer resistance were significantly higher in the bare soil compared with the soil under grass or legume cover. He also found that infiltration ratio, saturated hydraulic conductivity and the available water capacity of a degraded sandy clay loam were significantly lower in the bare soil and improved about 572.7, 485.4 and 45%, respectively due to the grass and legume cropping. Connolly and Freebairn[10] reported that maintenance of surface cover for soils that tend to form seals and crusts when bare is important to improve infiltration. They found that pasture successfully improved hydraulic conductivity of these soils with more than 35% clay. In another study by Bell *et al.*[23] increases in rainfall infiltration rate ranged from 70 to 400% due to cropping treatments. In this study cropping treatments showed the highest increase in the infiltration ratio compared with the other soil quality indicators. Infiltration ratio increased in the following order; bare soil<RG<CV<BR<AL<SB<SC. The highest increases in I and θ over the bare soil were found as 773.2% for the SC and 41.71% for the RG, respectively while the lowest increases were found in I of 289.3% for the RG and θ of 14.97% for the SB.

Relationships among the soil quality indicators: The positive effects of soil organic matter content on soil physical properties such as, aggregate stability, porosity, infiltration, have been given in numerous studies[1,7,28]. In this study, organic matter content gave the significant positive correlations with SSI (0.47*), F (0.44*), I (0.47*) and significant negative correlations with BD (-0.44*) and PR (-0.67**). Increasing organic matter content in the soil due to crop treatments caused increases in structural stability, infiltration ratio and porosity with decreasing bulk density. Lal *et al.*[1] reported that the vegetation with deep tap roots and the ability to provide quick cover caused high improvements in soil structure. The loosening effects of roots and increasing soil fauna over the bare soil can explain the decreases in bulk density and

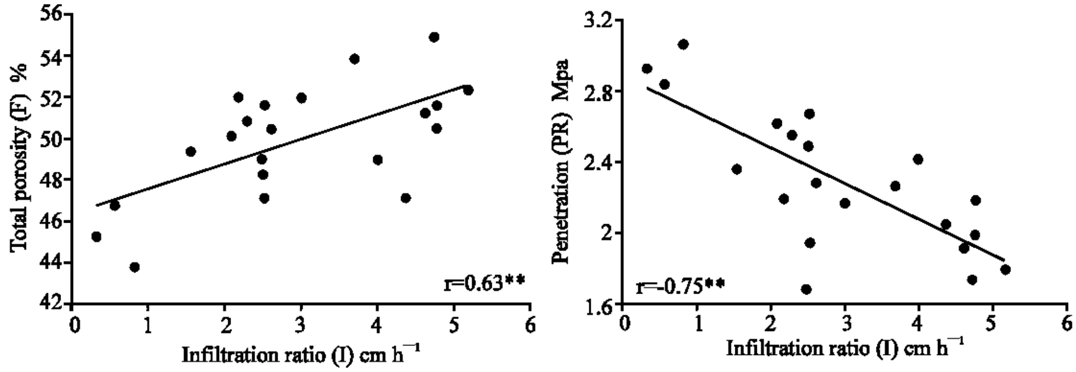

Fig. 1: Relationships among infiltration ratio (I), total porosity (F) and penetration resistance (PR)

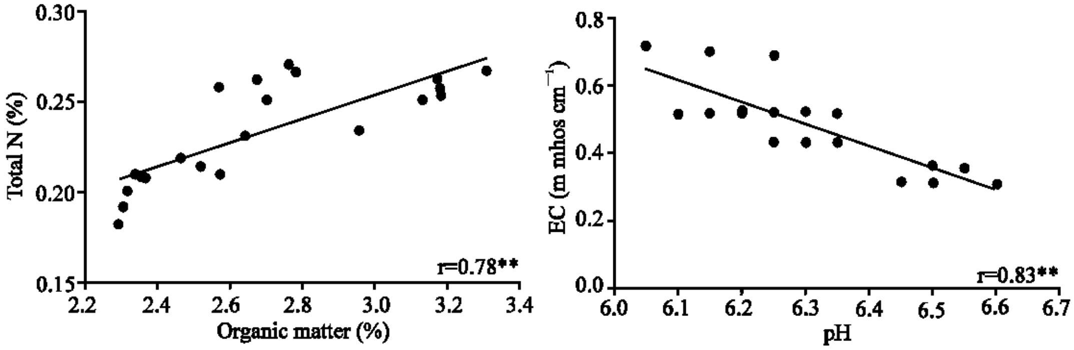

Fig. 2: Relationships among some chemical soil quality indicators

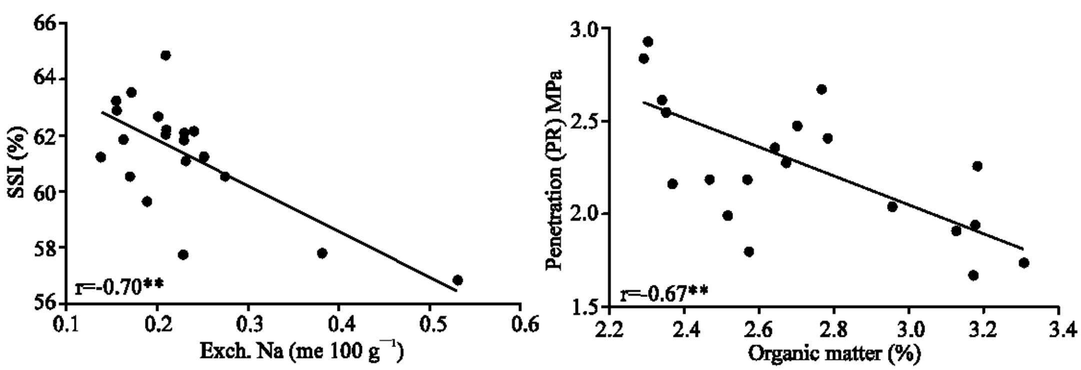

Fig. 3: Relationships between some physical and chemical soil quality indicators

increases in porosity and infiltration in this study. Infiltration ratio gave the highest significant positive correlation (0.63**) with total porosity and the highest significant negative correlation (-0.75**) with penetration resistance (Fig. 1). Infiltration ratio was also significantly correlated with SSI (0.57**), EC (0.47*), BD (-0.63**) and exch. Na (-0.53*). Arshad and Martin[5] reported that infiltration is influenced by the some other soil quality indicators such as; organic matter, aggregation, electrical conductivity and exchangeable Na content. The results of this study were also convenient with their statement.

The significant positive correlations among the soil chemical indicators were obtained between OM and total N (0.78**) and between pH and EC (0.83**) and are given in Fig. 2. Also some other higher correlations among the chemical indicators were found as fallows; OM x K (-0.84**), total N x K (0.51*), Na x EC (-0.47**) and Na x pH (0.46*). The higher correlation coefficient among the OM, exch. K and total N indicate that cropping treatment caused increases in nutrient contents of soil due to decomposition of organic matter or biological fixation through atmosphere by legume species. Eigenberg *et al.*[29] reported that field measurements of electrical conductivity identified the effects of manure, compost, fertilizer N and cover crop treatments on changes in available nitrogen contents. According to Arshad and Martin[5], available nutrient contents in soils are affected by the other soil quality indicators such as; organic matter, pH, texture, microbial activity. Bolinder *et al.*[30] concluded that organic matter content, nitrogen, microbial biomass carbon and soil carbon provided the most responsive soil quality indicators for different land soil management systems.

The significant negative correlations between physical and chemical indicators were obtained between SSI and Na (-0.70**) and between OM and PR (-0.67**) and are given in Fig. 3. OM, exchangeable Na content and EC were significantly correlated almost with all physical indicators. EC gave the significant positive relationships with SSI (0.52*), F (0.44*), θ (0.50*) and I (0.474*) and negative relationships with BD (-0.45*) and PR (-0.33). Exchangeable Na content also showed significant negative relationships with F (-0.50*), I (-0.53*) and significant positive relations with DB (0.51*) and PR (0.46*). These results indicated that other than soil organic matter, EC and exchangeable Na were useful indicators to define soil physical quality indicators under different cropping treatments.

All cropping species showed positive effects on the physical and chemical soil quality indicators. Increasing organic mater content due to cropping treatments caused considerable increases in soil structural stability, porosity, infiltration ratio, total N and K contents and also considerable reductions in bulk density, penetration resistance, pH and Na content over the bare soil. Most positive effects on the physical soil quality indicators and OM were obtained with bromegrass treatment. Total nitrogen and EC values were highly influenced by the alfalfa treatment. Organic matter content is one of the most important indicators of soil quality and has benefits for better aggregation and aggregate stability, longer cycling of nutrients, more water holding capacity and lower bulk density[31]. Besides organic matter content, EC and exchangeable Na content can be other soil quality indicators that define soil properties very well under different cropping treatments. Cover crops or ley pastures are accepted as a primary tool for reducing erosion and runoff by increasing surface residue and infiltration ratio[10,23,32]. All cropping treatments improved the infiltration ratio by increasing structural stability and porosity that can lead to the benefits of reduced erosion and improved soil water storage. As a result, some cover crop or green manure treatments, especially bromegrass and alfalfa, can be integrated in cropping systems to improve soil quality and for sustainable soil management.

ACKNOWLEDGMENT

The author thanks Dr. I. Ayan from the Agronomy Department of the Faculty of Agriculture at Ondokuz Mayıs University for her help during field studies.

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