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Effects of Crop Residue Burning on Soil Physical and Hydrological Properties in Semi-Arid Agricultural Production Systems

Rifat AKIŞ[1*]

[1]Mustafa Kemal University, College of Agriculture, Department of Soil Science and Plant Nutrition, Hatay
*e-mail: rakis@mku.edu.tr

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Abstract: The effect of wheat-stubble burning on soil physical and hydrological properties is under scrutiny to develop a sound soil and water management planning in agroecosystems. The objective of this study was to compare completely-burned, moderately-burned, and unburned soil conditions for responses of soil physical and hydrological properties. The persistence of fire-induced impacts were studied in 3 hectare land for both burned and unburned conditions for two years. Results showed that saturated hydraulic conductivity significantly increased in descending order 0.81, 0.36, and 0.23 cm h^{-1} for burned, moderately-burned, and unburned plots (P=0.000). Completely-burned treatments registered significantly higher Ksat (P=0.000) of 0.81 and 0.23 cmh^{-1}, respectively from completely-burned and unburned treatments. Fire intensity significantly reduced the pore space volume, the highest for burned and the least for the moderately-burned treatments (P<0.001). Unburned treatments had 11.5 and 9.7 % more pore spaces than completely-burned and moderately-burned plots, respectively. Residue burning significantly changed pore size distributions between three levels of treatments (P<0.045). Storage pores decreased significantly from 37.3% (unburned) to 25.8% (burned), while significantly increasing residual pores from 8.07% to 13.5 % (burned) and 12.7% (moderately-burned). To conclude, residue-retaining soil management practices need implemented in the Plain.

Keywords: Amik Plain, burned soil, dead pore, hydraulic properties, residue burning.

Bitki Artığı Yakmanın Yarı kurak Tarımsal Üretim Sistemlerinde Toprak Fiziksel ve Hidrolojik Özelliklerine Etkileri

Öz: Tarım ekosistemlerinde etkin bir toprak ve su yönetim planı geliştirmek için buğday saplarının yakılmasının toprak fiziksel ve hidrolojik özelliklerine etkisi araştırılmaktadır. Bu çalışmanın amacı tam-yakılmış, ortalama-yakılmış ve yakılmamış toprak şartlarında toprak fiziksel ve hidrolojik özelliklerinin durumunu karşılaştırmaktır. Yakmanın devam eden etkileri 3-ha alanda her iki yanmış ve yanmamış şartlarda 2-yıl çalışılmıştır. Sonuçlar göstermektedir ki: Suya doygunluk iletkenlik değerleri azalan sıralamayla, tam-yanmış (0.81), orta-derecede-yanmış (0.36) ve yanmamış (0.23 cm h^{-1}) önemli derecede artmıştır (P=0.000). Yakma şiddeti gözenek boşluk hacmini en fazla tam-yanmış ve en az da orta-derecede-yanmış muamelelerde azaltmıştır (P=0.000). Yanmamış muameleler sırsıyla tam-yanmış ve orta-derecede-yanmış muamelelere kıyasla %11,5 ve %9,7 daha fazla gözenek hacmi içermiştir. Bitki artıklarının yakımı gözenek büyüklük dağılımlılarını muamelelerin üç seviyesi arasında önemli derecede değiştirmiştir (P<0.045). Tam-yanmış muameleler sırasıyla yanmamış (0.89) ve orta-derecede-yanmış (0.79 cm-1) muamelelerden önemli derecede yüksek Ksat farkları göstermiştir (P=0.000). Bitki artıklarının yakılması depo gözenek hacimlerini %37,3 (yanmamış) den %25,8 (tam-yanmış) değerine önemli derecede azaltırken, ölü gözenek hacmi %8.07 den %13,5 'e (tam-yanmış) ve %12,7' ye (orta-derecede-yanmış) önemli derecede düşürmüştür. Bitki artıklarını toprakta tutan toprak yönetim uygulamaların ovada hayata geçirilmesine ihtiyaç vardır.

Anahtar Kelimeler: Amik Ovası, yanmış toprak, ölü gözenek, hidrolojik özellikler, anız yakma

1. Introduction

Residue burning in arid and semi-arid agroecosystems is a critical soil and water conservation management issue. The responses of hydrological properties and processes of soil to residue burning in semi-arid agriculture remains under scrutiny because the burned soils gain differential physical, chemical, and biological properties from the unburned original soil.

Depending on fire intensity, burned soils gain water-repellent conditions, poor soil infiltration capacity and increased erosion hazards (DeBano et al. 1998). Fire-induced hydrological conditions for rangeland ecology and forest ecology were well-catalogued (Shakesby et al. 1993; Rab, 1994). Open-burning crop residues in field produces hydrophobic components of organic matter, vaporizes big part of organic matter in the topsoil, and adversely affects the soil conditions. Wright and Bailey (1982) reported the degree and longevity of water-repellent soil conditions and control factors on water repellency were organic compounds of burning residue, burning intensity, and duration of the fire. Fire events destroy surface soil through destroying soil organic matter protection and thus decreasing infiltration rates in the soil. This results in reduced surface initial abstraction of rainfall, increased erosion, and runoff rates.

The distraction of fire on the surface soil can directly influence soil physical and hydrological properties. Fire effects on soil properties in surface horizons and/or epipedons are addressed as decrease in bulk density (Clinnick and Willatt, 1981), increase in soil aeration (McNabb et al. 1989), and increased risk of soil erosion (Mackay et al. 1985). Soil physical properties affected by logging were investigated in forest soils by Rab (1994 and 1996).

Residue burning has been very commonly applied to wheat, rice, grass-seed, soy, other grains, cotton, and corn in the U.S. (McCarty et al. 2007). Eiland (1998) reported fire was applied to remove excessive living biomass from sugarcane in subtropical region of the United States. Hemwong et al. (2008) reported about nitrogen fixation and residue decomposition dynamics when sugar cane residues were retained rather than burned in the field in Thailand. Similarly, in the Midwest states of the United States, burning of pastures and rangelands is also reported (Vermeire et al. 2004; McCarty et al. 2009), results of which could trigger very interesting environmental consequences such as shifts in hydrologic water budget in the dry Midwest States environment. As a result, burning crop residue can be an important local and regional agricultural practice depending on the countries. The environmental effects of open-field burning are reported to generate particulate matter and gas mixture emissions (Zhang et al. 2008; Ghimire, 2007). Burning crop residues directly produces heat, wave emissions of which may cause potential of ground level ozone to react with different gaseous emissions of soil nutrients, thus resulting in climate change (Auffhammer et al. 2006; EIA, 2008). Webb et al. (2009) reported heavy metals and dioxin concentrations in the emissions of gas mixtures sourced from residue burning. Malhi and Kutcher (2007) observed considerable nutrient losses (C, P, N, and others) by volatilization owing to the burning crop residues in the field. Yilmaz et al. (2012) found soil respiration rates significantly decreased after wheat stubble burning in the southeastern Turkish Plain soils of 0 to 3 cm depth and concluded that soil functions and bioactivity were strongly dependent on the retaining the stubble residues of wheat in those soils.

Aggregation is a key factor for soil structural development and sustainability and thus, soil functions that require retention of crop residues to foster soil organic carbon levels for soil aggregate and structural stability. Aggregation of soils are dominantly affected by soil management practices and considerably mediated by soil organic carbon content. Wang et al. (2010) observed the relations between fungal hyphae and cellulosic organic matter both increased the aggregation and aggregate stability in soil. Similarly, Bronick and Lal (2005) reported aggregate formation and stability increased as the fungal density increased in soil. Open burning of crop residuals are aimed at timely and budgetary management of the soil for the next crop (Gedde et al. 2009; Haider, 2013; Lal, 2008). Cerit et al. (2002) reported that stubble burning of wheat in Turkey is for enjoyable soil management. As a result, crop residue burning is not considered environmentally-sound and sustainable method for soil and residue management.

Field residue management differs from one region to another in Turkey. There are different accounts for this differential management practices because of soil moisture potential ranges and longevity of growth period of crop of interest. In one-cycle cropping areas in a year, where long and cold winter conditions prevail and sufficient precipitation and irrigation water occur, such as in Eastern Anatolia, Turkey, crop residues are used for herd production for winter feedings of livestock. Otherwise, animal grazing (cattle and sheep) continues to remove the residues from the field until the field will have been re-cropped for the next year. In the regions such as the Central Anatolia, Turkey, crop rotates once a year and climatological conditions provide long, dry and cold winters with insufficient precipitation and irrigation water for agriculture. In this dryland agriculture production system, crop residues are burned mostly in the field. Urbanization has been highly developed and population density and social-welfare are high on average in comparison to the case in the Eastern Anatolia region, Turkey. Therefore, postharvest residue is open-burned in the region. In two- and three- cycle cropping regions in Turkey, such as the Eastern Mediterranean region, where population density and social-welfare are higher than the ones for the Eastern Anatolia and the Central Anatolia regions and winters are long but mild with excessive precipitation and irrigation water, crop residues are burned for time-saving for the next crop-seeding, facilitating soil and crop management practices, and fighting with pests and diseases, sometimes. In all these regions, the most common plant and soil management problems, especially for soil conditions and grade of soil structure, are complete field burning, soil erosion, and soil nitrogen and phosphorous deficiency. This situation obviously commands to implement new rural development plans and projects by the government as soon as possible to better manage the behavioral response of farmers to residue burning in the field. Although the extent of land acreage exposed to burning is unknown for sure over conterminous Turkey, the common sense dictates that the first row is occupied by crop residue removal practice of herd production, followed by animal grazing, and then open-field burning. In general, wheat straw is mostly preferable to burn to the residues of corn, cotton, and sunflower residues in Turkey. Barley's herd and remnants are nutritious and easy to digest for livestock, and has a short life cycle of growth in the field against wheat growth, they are mostly used for animal husbandry whenever available, and therefore are not likely to burn in Turkey. Depending on the harvest height of the grain crop (i.e., barley and wheat), 3500 kg ha^{-1} for entire burning of crop residue and 1000 kg ha^{-1} for the remnants other than herds are lost without incorporation to soil (Temel, 2012; Yilmaz et al. 2012).

The objective of this study was to measure and compare the effects of open-field wheat residue burning on soil physical and hydrological properties for completely-burned, moderately-burned, and control plots in the Amik Plain, Turkey.

2. Methodology

Study Site Details

The study field is about 2.5 hectare (ha) area, cropped to wheat (Triticum aestivum). The research site (36^o.17^1 N, 36^o.11^1 E) is located near the university campus area, Büyük Dalyan, Hatay, Turkey. The harvest was on May 26, 2013. A typical soil profile in the site is sand and sandy loam and soil profile depth ranges from 90 to 162 cm in the field. The landform is flat with the slope <2%. The Plains soils predominantly consist of clayey texture because of the fluvially transported alluvial calcareous parent material accumulating in geologically young depressions in the Quaternary time (Kilic et al., 2008). The soils of research field are classified by Kilic et al. (2008) as poorly and somewhat poorly drained Typic Haploxerert. The soils have lime content between <1 % and above 5 % (Uygur et al. 2010; Kilic et al. 2008). Soil particle size analysis showed that the range of clay, sand, and silt percentage was between 9.21 and 34.8, 38.5 and 89.5, and 1.25

and 26.7 for completely-burned, 6.7 and 17.6, 74.6 and 90.1, and 2.2 and 9.9 for moderately-burned, and 8.3 and 35.1, 36.8 and 87.2, 2.8, and 38.3 for unburned treatments, respectively. These ranges for soil textural separates coincide with sandy loam and/or loamy sand in the study site.

Climatic Descriptions of the Study Field

The climate of the area is humid and semi-humid with mean annual rainfall of 1124 mm and evaporation of 1877 mm based on the last 50 years in the region. Climatic drought classing in the region also shows that the Amik Plain has Erinç Precipitation Indexes of 24-40 corresponding to semi-humid and 41-54 being humid meidterranean climate (DMI, 2016). The mean annual temperature is 18.1 ^{o}C. Percentage distribution of the rains in the region was registered as 35 % in winter, 29 % in spring, 12 % in summer, and 24 % in autumn (DSI, 1962). The most rain falls in winter while the summer is hot and dry. The spring and fall seasons are less wet than winter levels in the Plain soils. The wetter fall season starts by October (Korkmaz, 2005).

Soil Samples

The sampling design was a grid system and approximately 20 m x 20 m grids were used to collect the disturbed and undisturbed soil samples from 0-10 cm thickness of surface soil. In the unburned, moderately-burned, and burned fields, 36 undisturbed and 36 disturbed samples were collected with two replications. The same amount of sampling was repeated in the study site in the year after. The disturbed samples were run for soil texture and soil organic matter content analyses while the undisturbed samples were used for soil hydrologic properties. Soil particle size analysis was performed by hydrometer method (Day, 1965). Soil saturated hydraulic conductivity, Ksat, was measured in the soil core samples through constant head Darcy permeameter in the University's soil physics and drainage research laboratory (Klute and Dirksen, 1986).

Crop Rotations and Burning Residue in the Field

The cropping pattern in the area includes winter-wheat (Triticum aestivum L.) and cotton (Gossypium hirsutum L.) for the two cycle cropping period in rotation. Two cropping periods exist between middle of spring and late autumn seasons in the Amik Plain soils. The study site was cropped to winter wheat and harvest was performed on May 26. The field was divided approximately in three equal 1-ha plots. The soil sampling was conducted on one transect in the same direction in each parcel. One parcel was completely burned, indicating no crop residue was describable after burning, another one was moderately burned, indicating that some parts of the residue after burning was still distinguished, and the other one was kept untouched for control treatment in the experiment.

RETC Model

Characterization of Water Retention Curves

Undisturbed soil samples were collected by soil cores of 5 cm height x 5 cm diameter from the surface soil with two replica. Soil saturated hydraulic conductivity (Ks) was measured for each core sample. Bulk density, porosity, water retention curves (WRC), and soil hydraulic parameters were determined on the undisturbed soil core samples in the laboratory. Starting from saturation water content, water discharges during successive matric potential decreases was measured on both tension table and porous pressure plate successively at 0, -10, -15, -33, and -1500 kPa. The van Genuchten (1980) and Mualem (1976) equation was fitted to the data points.

Model Description

Water retention characteristic of the soil was simulated using RETC code. The model inputs the observed and calculated retention model parameters and then, simulates for the optimal hydraulic model parameters with the lowest mean squared error term and explained variance of R^2

between observed and simulated measurements of each parameter.

The van Genuchten (1980) model is given as the following.

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1 + (\alpha|h_m|)^n]^m} & h \leq 0 \\ \theta_s & h \geq 0 \end{cases} \qquad (eq.1)$$

$$K(h) = K_s S_e^l [1 - \left(1 - S_e^{\frac{1}{m}}\right)^m]^2 \qquad (eq.2)$$

$$m = 1 - \frac{1}{n} \qquad n > 1 \qquad (eq.3)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (eq.4)$$

Where, $\theta(h)$ is water retention curve function, θ_r the residual volumetric water content, θ_s saturated volumetric water content, h_m is the matric head (cm). The parameter α is air-entry parameter and m and n are retention curve fitting parameters. $K(h)$ is unsaturated hydraulic conductivity function computed from the water retention curve. K_s is saturated hydraulic conductivity. S_e is the reduced water content and l is the pore connectivity parameter with an estimated value of 0.5 (Mualem, 1976). The residual water content, θ_r, is the water content value blow which water no longer be removed from the soil by plants and it is equal to wilting point water content of sandy soils. The hydraulic parameters of soil, θ_r, θ_s, α, and n, were initially determined from the measured soil water retention data according to van Genuchten (1980) computational steps. Then, they were optimized using the RETC software by fitting retention data (*θ-h* relationship) (van Genuchten et al. 1991).

Measurement of Pore Size Distribution and Available Water

Soil core samples were used for bulk density, total porosity, air-filled porosity and water-filled porosity (pore diameter < 30µm). Water content at saturation was determined immediately after saturation process in the laboratory. Saturated core samples were placed on tension table and allowed to dry upto -5 kPa water potential. Then, volumetric water content at -33 kPa was determined in the core samples for field capacity. Water-filled porosity was calculated from the volumetric water content at -5kPa. Air-filled porosity was calculated as the difference between saturation water content and water content at -5 kPa. Pore volume <0.2 µm (residual pores) was determined by volumetric water content at the permanent wilting point (PWP, 1500 kPa). Available water (AW) was determined as the difference between water contents of field capacity and permanent wilting point, respectively.

Measurements of Infiltration Rate and Cumulative Infiltration

A double ring infiltrometer was used to perform infiltration measurements in the field. Vertical infiltration was calculated with two-parameter Philips equation.

$$i = \frac{1}{2} S_i t^{1/2} + A \qquad (eq.5)$$

$$I = \frac{1}{2} S_i t^{1/2} + At \qquad (eq.6)$$

Si is soil sorptivity (cm.h$^{1/2}$) and depending on initial water content of the soil and pore geometry of the soil. Term *A* is related to soil hydraulic conductivity (cm.h^{-1}) (Philip, 1969), *t* is the elapsed time (h) in the infiltration test, the term *i* is the infiltration rate at a certain time(cm.h^{-1}) of measurement, and *I* is the accumulative infiltration depth (cm).

Statistical Analyses

The data were analyzed using One-Way Analysis of Variance (ANOVA). ANOVA produced one-way analysis of variance for a quantitative dependent variable by a single factor (independent) variable. ANOVA tested the hypothesis that several means were equal. A post hoc test in ANONVA was used to compare means at 95% confidence interval and alpha of 0.05. Within- and between groups variances were determined in ANOVA. Tukey's honestly significant difference test (HSD) and the least significant difference (LSD, $P<0.05$) values were calculated from the residuals from the analysis of variance. Burned and unburned soil properties were compared. IBM SPSS Statistics 22.0 statistical package was used to perform the ANOVA and other procedures.

3. Results and Discussion

Soil Hydraulic Parameters

ANOVA test showed a significant effect of stubble burning on soil infiltration processes (P=0.000). Moderately burned plots measured 12.5 mm and 6.8 mm more significant infiltration depth (P=0.000) than unburned (P=0.049) and completely burned plots (P=0.05), respectively (Table 1). Residue burning was significantly effective on infiltration rates and accumulative infiltration regardless of treatments. Imeson et al. (1992) studied the complexity of infiltration in fire affected soils and documented four types of infiltration curves. Although type 1 and type 2 curves of infiltration were explained by traditional theory of infiltration, type 3 and 4 were explained by water repellency which should be incorporated in the traditional theory of infiltration.

According to type 3 and 4 curves of Imeson et al. (1992), soil has initially low infiltration rates that increase as the soil becomes saturated. Eventually, the rates decline with increased wetting. As a result, increased infiltration rates are a result of water repellency and macropore flow which are spatially variable (Nyman et al., 2010).

Soil bulk density was not significantly affected by fire levels at all (ANOVA, P=0.075). No significant differences between burned and unburned treatments were found. The unburned and moderately burned treatments showed the only outstanding effect of residue burning on the mean difference (0.42 g cm^{-3}) of soil bulk density values, although not significant (P=0,061). The mean bulk density for moderately-burned soil was 43% and 30% lower than those of unburned and completely-burned treatments, respectively. This contradicted to the results of Giovannini et al. (1988) that reported bulk density increases as a result of disrupting organo-mineral complexes due to fire effect on aggregates and pore clogging because of free clay minerals and ashes (Durgin and Vogelsang, 1984).

Although not significant, residue burning tended to reduce bulk density by 15.4% after fire in all the burned plots in comparison to unburned plots. Rab (1994) also reported even larger values of bulk density decreases in their forest experiments with different levels of fire intensity in disturbed topsoil plots and related these decreases to the soil's texture, organic matter content, and profile disturbance. The highest bulk density was registered in the unburned plots while the lowest bulk density was always registered in the moderately-burned plots. The hardest problem with the moderately burned sandy loams or loamy sand textures was that the stubble ash was a complete admixture intra- and inter-aggregates tested in the laboratory and mean bulk density is likely to decrease as a result. There can be a piece of char formation, a survival part of incomplete combustion of vegetative residuals in soil that can reduce soil bulk density (Baldock and Smernik, 2002). Critical levels of soil bulk density has not been known for the Amik Plain soils and random burning or prescribed burning of crop residues must be well judged because seedling or seed emergence could be critically hampered. In fact, the observation in the current study site for two years after experiment thought the field practitioners that soil did not produce its 1/3 of natural potential fertility after burning. The research field remained fallow for at least one year after the experiment finished although the field had been planted for winter wheat again.

The completely-burned treatments measured significantly higher Ksat values than the other treatments (P=0.000) and the mean values of Ksat were recorded as 0.81 and 0.23 cm h^{-1}, respectively for the completely-burned and unburned treatments. However, there was no significant difference between moderately burned and unburned treatments for the mean Ksat values (Table 1). This shows that residue burning increased Ksat values significantly higher levels than unburned conditions. Although the results showed very significant increases in Ksat of burnd soils, the Ksat values are entirely covered by the reportedly reduced values (Ksat of 1-100 mm h^{-1}) after a fire event (Imeson et al., 1992; Yates et al., 2000; Moody et al., 2009; Robichaud, 2000).

ANOVA did not show any significant differences for the means of Θs, Θr, α, and n parameters of soil hydrological model parameters among treatments. The only weak significance was observed between burned and unburned treatments for soil alpha parameter (P=0.071) and soil moisture retention curve's shape parameter n (P=0.09) (Table 1). However, one-sample t-Test compared one sample of the hydrological model parameters to a known population mean in a pairswise manner and each sample was significantly different from the other in the sample pairs (Table 2). One sample t-Test proved no significance between the sample pairs for soil α parameter as was the case in the ANOVA test (Table 1). Soil α parameter was coming from the same sample population and they were practically the same, while the other hydrological model parameters were significantly different from the sampled population mean (Table 2).

Table 1. Cumulative infiltration depth, Bulk density, saturated hydraulic conductivity and optimized retention parameters for burned, moderately burned, and unburned wheat field soils (95% confidence intervals)

Çizelge 1. *Tamamen yanmış, orta derecede yanmış ve yanmamış buğday tarlası topraklarının eklemeli sızma miktarı, kuru hacim ağırlığı, doygunluk hidrolik iltekenliği ve optimize edilmiş su tutma parametreleri (%95 güven aralığıyla hesaplanmıştır)*

Conditions	Cumulative Infiltration, I, mm	Bulk Density (ρ_b), g. cm^{-3}	K_{sat} at 29 ^oC (cm. h^{-1})	Θ_s , cm^{-3} /cm^{-3}	Θ_r , cm^{-3} /cm^{-3}	α, cm^{-1}	n
Burned	**14.37±2.87*****	1.04±0.08	**0.81±0.11****	0.478±0.02	0.135±0.008	0.0042±0.0004	2.293±0.065
Mod. Burned	**21.18±2.75*****	0.8±0.17	0.36±0.05	0.505±0.007	0.081±0.041	0.0058±0.0009	1.956±0.272
Unburned	**8.66±2.39*****	1.23±0.12	**0.23±0.02****	0.512±0.07	0.123±0.016	0.0066±0.0009	1.831±0.033

*,**,*** Bold figures and the symbols indicate significance at 0.05, 0.01, and 0.001levels, respectively. Mod. Burned: Moderetaly Burned

Table 2. The *p*-values for Student's *t*-Test for difference in mean hydraulic parameters (at the 95% confidence level, significance for two-tailed)

Çizelge 2. *Ortalama toprak hidrolik parametreleri arasındaki farkı gösteren öğrenci t-Testi'ne ait p değerleri (2-kuyruklu t-Testi önemlilik derecesi %95 güven aralığıyla hesaplanmıştır)*

Conditions	SOM, %	Bulk Density (ρ_b), g. cm^{-3}	I, mm	K_{sat} at 29 ^oC (mm. h^{-1})	Θ_s , cm^{-3} /cm^{-3}	Θ_r , cm^{-3} /cm^{-3}	α, cm^{-1}	n
Burned	0.000	0.000	0.000	0.000	0.002	0.003	0.007	0.001
Mod. Burned	0.000	0.003	0.000	0.000	0.000	0.191	0.025	0.019
Unburned	0.000	0.000	0.000	0.000	0.000	0.018	0.018	0.000

Mod. Burned: Moderetaly Burned

Soil Particle Size Distribution

The effect of residue burning on soil particle size distribution and soil texture was significant (ANOVA, P=0.028) (Table 3). A significant difference in soil texture was found for moderately-burned and completely-burned treatments compared to unburned treatments. Oswald et al. (1999) reported soil particle size is not to change as a result of fire effects. Therefore, particle size changes in a burned soil could be a result of indirect effects of fire but also direct effect of climate and topographic characteristics of a landscape on soil properties. A selective removal of soil particles through erosion can result in particle size change in the landscape (Mermut et al., 1997) and can be more detrimental to soil than water repellency (Marcos et al., 2000; Shakesby et al., 1993).

The perception of the effects of residue burning in the current study is that well-occluded organic matter in silt and clay sizes was lost to fire intensities in completely burned and moderately burned plots. This may have resulted in significantly lower percentages of post-fire silt and clay fractions in comparison to the unburned treatments. Contrasting to soil silt and clay content after fire, soil sand content showed a significant increase. This does not necessarily mean net-gains of sand particles in the soil after fire. On the other hand, residue burning caused a great portion of soil organic matter loss from the soil but also soil organic carbon distillated, as a result of which volatilized organic compounds moved downward the soil profile (<8-10 cm depth) and condensed on the surfaces of aggregates and single grains that yielded in a significant increase in soil sand fraction. In fact, depending on the soil ecosystem resilience, the condensed hydrophobic materials disappear through mineralization processes in time and the other method to destroy the hydrophobic meterials in soil is to expose the soil to higher temperatures above 500 ^{o}C (Certini, 2005).

The other reason for the soil particle size change could be the transformation of fresh organic matter to some recalcitrant forms of soil organic materials that may exhibit different particle sizes in a burned soil (Certini, 2005). Fernandez et al. (1997) evaluated soil organic C at different temperatures ranging from 150 to 490 ^{o}C in a qualitative manner. They reported that moderate temperatures (i.e., 220 – 350 ^{o}C) initiated thermochemical prolysis of soil carbon while the lowest temperature was totally ineffective on this transformation and the highest temperature completly oxidized the the soil C. On the other hand, intermediate temperatures were responsible for the major structural change from soil organic C to char formation in their soil. The char formation can also have a role in soil particle size change, as a result.

The other reason for particle size change after residue burning was reported by Schwertmann and Taylor (1989). They reported Fe-oxide formation from pedogenic Fe-oxides at 300-425 ^{o}C in soil. The formation of this material can also results in a definite particle size that can be translated in fractions of soil particles which may eventually cause a particle size change after a fire event in soil. In the current study, weather or not dispersing agent of calgon (sodium hexametaphosphate) is more effective on organo-mineral assemblages or aggregate stability than fire intensity to yield into more fine fraciton of aggregates need a detalied scrutiny. In addition, a wet seiving test and a sophisticated spectroscobic method can reveal how a humic chain materials evolve or speed into a different shape of certain size of fractions in a soil under fire. None of these questions were covered in the scoope of this study.

The mean difference of sand contents between unburned and moderately burned treatments was 14.97% ($P<0.008$) and the moderately-burned treatments had the highest sand content (81.75±5.79) among treatments.

The means of silt content did not differ from each other significantly among treatments (ANOVA, $P=0.072$). There was an only significant mean difference (7.9%) for silt content between the moderately-burned and unburned treatments ($P=0.025$).

Clay content of the treatments were significantly different from each other (ANOVA, $P=0.028$). Moderately-burned treatments had significantly lower clay content (8.5%) than the unburned treatments ($P=0.009$) (Table 3). Type and amount of fuel availability, weather conditions and timing of burning can lead to change in particle size distribution in moderately burned treatments. Rab (1996) reported high intensity fire triggered clay content decrease and silt content increase in forest soils and Giovannini et al. (1988) observed clay and silt content decreased while sand content increased under high intensity fire above 220 ^{o}C. Change in particle size distribution may reflect topsoil loss, and movement that worsens the topsoil quality for the next cycle cropping.

Table 3. Effects of fire on particle size distribution

Çizelge 3. *Toprak tane dağılımı üzerine anız yakma ateş şiddetinin etkileri*

Conditions	Sand, %	Silt, %	Clay, %	SOM, %	Textural Class
Burned	73.03±5.79	12.13±2.57	14.84±2.39	1.89±0.14	Sandy Loam
Mod. Burned	81.75±5.79	6.03±0.84	11.71±1.01	1.86±0.13	Sandy Loam
Unburned	**66.78±5.29*****	**13.91±2.75*****	**20.21±1.63*****	2.17±0.09	Sandy Loam

*, **, *** bold figures and the symbols indicate significance at 0.05, 0.01, and 0.001levels, respectively. Mod. Burned: Moderetaly Burned

Soil Organic Matter and Bulk Density

Soil organic matter content was the highest for the unburned plots. However no significant differences between- and within- groups of residue burning treatments for SOM were observed in comparison to other treatments (P=0.102) (Table 3). After burning the residues, the unburned plots held 16.7% and 14.8% higher organic matter than the moderately-burned plots and completely-burned plots, respectively. Relatively low SOM levels in the treatments may have reduced the effects of burning and reduction of organic matter further.

SOM and bulk density behaved very similar to each other and no significant effects of burning on bulk density were evident in ANOVA analysis. Table 3 shows that the highest SOM content (2.17%) was measured in the unburned plots that may be as a result of soil management practices for years. The SOM tended to decrease in the order unburned > burned> moderately -burned because of long years of soil and crop management practices (Table 3). Removal of organic matter from the soil not only breaks down the soil aggregates, but also limits new aggregate and soil structure formation through its cementing capacity, loss of which results in lacking large stable aggregates to combat soil erosion. Mataix-Solera and Doerr (2004) observed that structure stability increased by low to moderate fires that formed a hydrophobic coating on the external surface of aggregates. Badia and Marti (2003) reported aggregate stability decreases when organic cements were lost to fire. Soil organic matter is also a critical source of phosphorous, nitrogen, and Sulphur in soil. Therefore, loss of soil organic matter through burning has a great potential to reduce soil fertility to poor levels (Hemwong et al. 2008).

The relationship between bulk density and organic matter content of the burned soil treatments (completely and moderately burned treatments) is presented in Figure 1. The slope coefficient (-0.383) was significant at 1% level (P<0.011), with standard error of mean= 0.282, student's-t test value= 2.764, n= 27 samples, and R^2= 0.36. This shows the challenge and importance of maintaining or improving organic matter levels in the regions soils rather than burning organic residues in these soils.

Soil bulk density decreased exponentially as the SOM increased in years. The exponential relationship showed the decrease in bulk density could be 0.31% if the SOM changed 1%. Upon thinking about semi-arid Mediterranean climate, one can imagine how hard it is to reconstruct soil organic matter levels to by far highest to maintain soil aggregation and structure in this sandy loam and/or loamy sand. On the other hand, soil degradation because of the burning of residues increases its pace against soil organic matter amendments in the region.

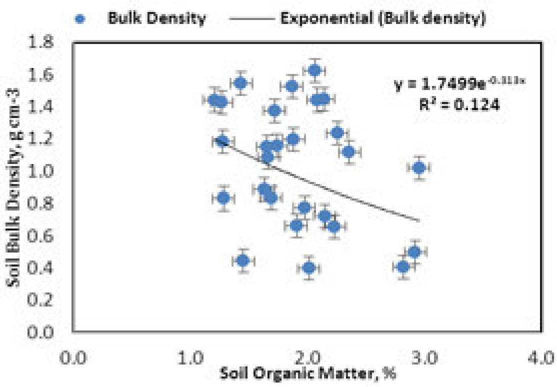

Figure 1. Soil bulk density and organic matter content relationships in burned soils in the Amik Plain.

Şekil 1. *Amik Ovası'nda yanmış toprakların kuru hacim ağırlığı ve organik madde miktarı ilişkileri*

Soil Pore Size Distribution and Available Water

No significant differences in available water potential were observed among treatments (Table 4). Rab (1996) observed the same result from slush and burn practice of agriculture. Residue burning increased volume of macropores and decreased the volume of micropres, yet, resulting in insignificant differences in total porosity (Tarrant, 1955). Available water potential decreased in the order of unburned >moderately-burned>completely-burned treatments. Exactly the same trend occurred in air-filled porosity of the treatments and no significant mean differences were observed for air-filled porosity between the three levels of fire treatments. The results also showed that air-filled porosity ranged from 1.73±1.89 to 5.1±1.89. This limit is lower than critical level 10% for soil aeration and root proliferation. Oswald et al. (1999) reported loss of organic matter in soil reduced soil exchange capacity that also available water and water holding capacity in the soil.

ANOVA uncovered significant effects of residue burning on pore size distribution and soil pore classes (P<0.001). Storage pore volumes between 30 and 0.2 µm significantly differed in their means for completely-burned and unburned treatments (P<0.001) and for unburned and moderately-burned (P<0.002), while moderately-burned and burned treatments were not significantly affected in terms of their mean difference of storage pores. As a result, storage pores decreased significantly in completely burned versus unburned treatments. Soil may have lost some pore space volume upon burning because the mean difference between unburned and burned is higher for the shake of unburned treatments (Table 4). Similarly, moderately-burned and burned treatments had a higher mean difference of storage pores, being higher for moderately burned treatments. This meant soil storage pore volume decreased in completely-burned and moderately-burned treatments, in which particle size significantly changed from the unburned treatments (Table 3). ANOVA revealed a very significant effect of fire intensity on dead pores of <0.2 um (P<0.003). Completely-burned treatments had the significant and highest amount of dead pores (pores<0.2 um) (P<0.045) and moderately-burned treatments had significantly higher amount of dead pores than unburned plots (P<0.05). Completely-burned and moderately-burned plots did not show any significant mean difference between their dead pore volumes as as the case for storage pores. Consequently, significant amount of residual pore formation in both of the burned treatments may be attributed to the decreasing tendency in soil bulk density.

Table 4. The effects of fire on pore size distribution (measured samples)
Çizelge 4. *Anız yakma ateş şiddetinin ölçümü yapılan örneklerdeki gözenek dağılınına etkileri*

Conditions	Available pater potential (AWP), %	Air-filled porosity (>30µm), %	Water-filled pores, %	
			Retention pores (30<P<0.2µm)	Residual pores (<0.2µm)
Burned	16.77±1.95	1.73±1.89	**25.8±1.55*****	**13.5±1.71*****
Mod. Burned	17.13±1.95	2.73±1.89	27.6±1.55	**12.7±1.71***
Unburned	19.8±1.95	5.1±1.89	**37.3±1.55*****	8.07±1.71

*,**,*** bold figures and the symbols indicate significance at 0.05, 0.01, and 0.001levels, respectively. Mod. Burned: Moderately Burned

Water Retention Curves and Soil Hydrologic Model

Unburned and moderately burned soil retained higher amount of water in wet area (pressure head between approximately 0 and 80 cm) than completely-burned treatments, indicating that completely-burned treatments had large amount of transmission pores rather than retention pores in the pressure head range 0-80 cm (Figure 2). This is also evident from small alpha value (α) range 0.0035-0,046. The lower air- entry value becomes, the lower amount of water retains in soil. The air-entry value for burned treatments ranged from 286 cm^{-1} to 217 cm^{-1}, for moderately-burned soils from 222 cm^{-1} to 217 cm^{-1}, and for the unburned soils from 192 cm^{-1} to 121 cm^{-1}. In the dry area or the water retention curve, dead pores are the highest in the completely burned treatments and the lowest in the moderately burned treatments. On the other hand, the unburned treatments were unaffected by the fire, and thus no significant change in the dead pores (Figure 2).

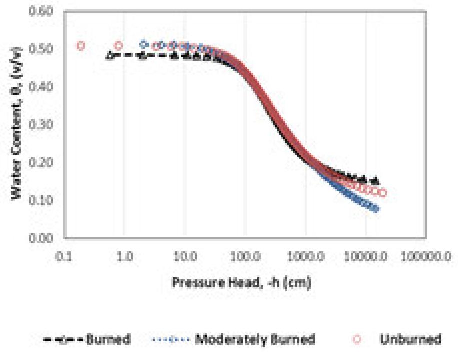

Figure 2. Water retention data for the three soil conditions
Şekil 2. *Yanmış üç toprak koşullarına ait su tutma verileri*

Since the water retention capacity was low, soil hydraulic conductivity that was relatively high was more important than water content in the burned treatments, except unburned treatments. Therefore, Ksat was found very significant in ANOVA tests.

4. Conclusions

The changes in soil physical and hydrological properties as affected by wheat stubble-residue burning with different intensities were investigated. Wheat stubble-burning resulted in significant changes in soil infiltration rates and cumulative infiltration depths in burned treatments. Soil hydraulic conductivity was very significantly impacted by the induced fire intensities so that between burnt and unburned treatments registered 0.58 cm^{-1} Ksat mean difference. Fire intensities changed the soil texture significantly from the unburned treatments and there existed a very significant difference between sand, silt, and clay separates between three levels of residue burning in the study field. Soil bulk density was unaffected by the residue burning. However, moderately-burned treatments had characteristically lowest bulk density values (0.8 g cm^{-3}) most probably because of inadequate soil excess water drainage management practices and undecomposed inert organic matter. Soil and crop management practices and geological origin of field, topography, and relatively high inert organic matter content for long years may have collectively caused low bulk density conditions for this treatment. In general, soil bulk density decreased as the soil's organic matter increased for the burned treatments. Soil pore size distribution and pore classes were significantly affected by the residue burning that reduced the amount of transmission pores between 0 and 80 cm pressure head range for the burned treatments against unburned treatments and increased dead pores between 7500 and 15000 cm pressure head range for the completely- and moderately-burned treatments. As a method of seedbed preparation, enjoyable soil management, and time and energy saving, residue burning and removal is not a viable and sustainable practice in the Amik Plain soils because this study uncovered that residue burning just increased a catastrophic situation for soil erosion and organic matter losses, thus lowering soil fertility and conservation potential. Therefore, new soil technology and tillage systems should be implemented to capture whole advantage of soil hydrological and productive potential. Retaining residues in soil by deeply burying and enriching nitrogen can be an alternative to residue burning in the Plain's soils so that sustainability of prosperous soil conditions can be monitored and maintained.

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