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Changes in Some Soil Chemical and Biological Properties on the Growing Season of Sesame in Çukurova Region

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A B S T R A C T

In present study, some soil characteristics of *Sesamum indicum* L. (Sesame) and its adjacent blank field (control) were compared in a growing season as pre (Pre_C and Pre_S) and post ($Post_C$ and $Post_S$) harvest in Adana, Turkey. Soil macro (C, N, P and K) and micronutrients (Cu, Zn, Mn and Fe), carbon (C_{min}) and nitrogen mineralizations and soil aerobic bacteria and fungi counts were determined in before and after harvest soils. Soils were humidified at 80% of their field capacity and then monitored for 45 days at 28 °C to determine soil carbon (C_{min}) and nitrogen (N_{min}) mineralization. Generally, macro and micronutrients (Cu, Zn, Mn and Fe) were higher in control than sesame field except phosphorus (P_2O_5) and there were found significant differences between them before and after harvest. Aerobic bacteria and fungi populations were decreased after harvest while fungi populations were increased in sesame soils compared to control. Soil CO_2-C evolution was higher in sesame field than control. Rates of carbon mineralization was in order as following $Post_C < Pre_C < Post_S < Pre_S$. Rate of N_{min} was significantly higher in sesame soils before harvest but it was lower after harvest compared to control. Carbon mineralization rates in sesame grown soils were significantly decreased and it was in order as following $Post_C < Pre_C < Post_S < Pre_S$. Decrease in soil carbon mineralization after harvest can be explained with decrease in soil microbial populations in short term.

Türk Tarım – Gıda Bilim ve Teknoloji Dergisi, 6(12): 1802-1808, 2018

Çukurova Bölgesi'nde Susam'ın Büyüme Periyodunda Toprağın Bazı Kimyasal ve Biyolojik Özelliklerindeki Değişimler

M A K A L E B İ L G İ S İ

Araştırma Makalesi

Geliş 25 Temmuz 2018
Kabul 19 Ekim 2018

Anahtar Kelimeler:
Toprak besin elementleri
Sesamum indicum L.
Karbon ve Azot mineralizasyonu
Toprak mikrobiyal sayımları
Mikrobiyal aktivite

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Ö Z

Mevcut çalışmada Adana, Türkiye'de *Sesamum indicum* L. (Susam) yetiştirilen ve bitişiğindeki boş bir arazide (kontrol) toprakların bazı özellikleri bir büyüme periyodu içinde hasat öncesi ($HÖ_k$ ve $HÖ_S$) ve sonrası (HS_k ve HS_S) olarak kıyaslanmıştır. Bu amaçla hasat periyodu öncesi ve sonrası alınan toprakların makro (C, N ve K) ve mikro (Cu, Zn, Mn ve Fe) element içerikleri, karbon (C_{min}) ve azot mineralizasyonu (N_{min}) ile total aerobik bakteri ve mantar sayımı yapılmıştır. C_{min} ve N_{min} için topraklar tarla kapasitelerinin %80 oranında nemlendirildikten sonra 28 °C'de 45 gün boyunca izlenmiştir. Genelde, fosfor (P_2O_5) hariç kontrol toprağında makro (C, N ve K) ve mikro (Cu, Zn, Mn ve Fe) elementler susam tarlasından daha yüksek olup, hasat öncesi ve sonrasında önemli farklar bulunmuştur. Bütün topraklarda aerobik bakteri ve mantar popülasyonları hasat sonrasında azalırken, susam topraklarında mantar popülasyonu kontrole göre artmıştır. N_{min} oranı 45 günlük inkübasyondan sonra önemli düzeyde en düşük HS_S'da bulunmuştur. Susam toprağındaki CO_2-C oluşumu kontrol topraklarından daha yüksektir. Susam topraklarındaki N_{min} oranı kontrole göre hasat öncesinde yüksek iken hasat sonrasında düşmüştür. Sadece susam topraklarında karbon mineralizasyon oranlarında önemli bir düşüş olup $HS_k < HÖ_k < HS_S < HÖ_S$ olarak sıralanmıştır. Hasat periyodu sonrası toprak karbon mineralizasyonu azalmış olup bu sonuç kısa dönem içindeki mikrobiyal popülasyonlardaki düşüş ile açıklanabilir.

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Introduction

One of the most important natural resources for crop production is soil that is essential for food needs of humanity. It is required to understand the limitations of soil environment and avoid damaging soil quality for efficient crop production. Soil is composed of clay, silt and sand particles, organic materials originating from the living and dead of flora and fauna. Plant root systems take water and nutrients from soil for continuous growth and development of plants (Khalil et al., 2015). Therefore, soil is considered as a living being that has a vital and key role in the terrestrial ecosystems by maintaining a balance between living and dead organisms. In general, soil consists of 2-5% organic particles, 20-45% minerals, 10-25% water and 15-25% air. But these rates may be variable in different types of soil due to environmental conditions. Soil quality is variable because of variation of these components and not all soil types are sufficient for growth of crops (Khalil et al., 2015). Thus, it is very important that soil quality must be evaluated by analyzing the physical, chemical and biological properties of soil before crop production.

Soil chemical properties consist of two groups: organics (by decomposition of plant and animal residues), and inorganics (Cu, Zn, Mn, Fe etc.). These properties such as nutrient contents and pH are very important in soil formation and crop production (Boix-Fayos et al., 2001; Salehi and Maleki, 2012). Soil macro and micronutrients play a key role in enhancing plant growth, soil structure and water penetration, and in increasing in soil biological activity, control of soil erosion and prevention of surface sealing. Soil pH level maintains the organic matter decomposition that leads to increase the amounts of soil phosphorus and manganese and is also a great indicator of nutrient cycling that increases in pH stimulate the adsorption of minerals (Khalil et al., 2015).

A highly complex community of microbes includes bacteria and fungi live as biological properties of soil and they play an effective and key role in nutrient cycles and plant growth (Hayat et al., 2010). Soil microorganisms use organic matter as an energy source that causes a flux of CO_2 from soil into the atmosphere called as soil carbon (C) mineralization. Nitrogen (N) mineralization, which is always bound with C mineralization, supplies a flux of labile N to plants and stimulates the sequestration of carbon through plant growth. Therefore, both soil C and N cycling by soil microorganisms maintain C balance in terrestrial ecosystems (Tian et al., 2017).

Monitoring soil chemical and biological properties during the growth stage of a plant can help us to understand the agricultural ecosystem and give insight about how to support a stable and sustainable agricultural system. Leogrande et al. (2014) researched the effects of different irrigations and organic fertilizers (mineral fertilizer, commercial stable manure, anaerobic digestate and municipal solid waste compost) on soil properties of eggplant crop in a three-year field experiment and reported that anaerobic digestate and compost reached the highest levels of soil total organic carbon. Dixon et al. (2016) studied that impacts of weed management (nonweeded, hand-weeded, and weed mat) and irrigation (throughout the summer and none postharvest) on soil organic matter and nutrients (potassium, calcium, copper, manganese and zinc) for two years in blackberry (Rubus L. subgenus Rubus Watson) and reported that these nutrients were were higher under higher weed mat than hand-weeded plots. They also indicated that soil K was below recommended standards during the study despite fertilization.

The present work was aimed at evaluating the some soil chemical and biological properties in beginning and end of growing period of sesame. It was hypothesized that temporal changes in a growing stage of sesame may decrease soil chemical and biological properties in sesame soil compared to control. This type of research is required to understand and explore changes in soil microbial activity in a harvest period and provide scientifically based information to support a decision regarding evaluation of soil quality before and after crop production and agroecological conditions.

Material and Methods

Study Site and Soil Analysis

Soils were taken from a sesame field and its adjacent blank field (no plant grown, used as control) at a soil depth of 0-10 cm in Research Farm of Cukurova University in Adana-Turkey (35°18′ E latitude, 37° 01′ N longitude, and 23 m above sea level) in July 2016 (before harvest) and October 2016 (after harvest). Soils were classified as Menzilat series. Following agricultural practices were applied in sesame field Conventional tillage was applied before sowing. Sprinkler irrigation was established immediately after sowing and thereafter used when necessary based on soil and plant conditions. Nitrogen, phosphorus and potassium were applied at a rate of 6 kg per decare at sowing as a complete fertilizer. An insecticide (Emamectin benzoate, 5% active ingredient, 30 g da^{-1}) was applied in sesame field for the elimination of cotton bollworm (*Helicoverpa armigera* Hübn.). Weedings were carried out by hand weeding and no herbicides were applied during the growing seasons (Kurt et al., 2016).

Six replicates were taken from each field and then homogenized. Soil samples were air-dried and ground to pass through 2 mm sieve for chemical analysis. Soils were coded as following: Pre_C and $Post_C$ for control, Pre_S and $Post_S$ for sesame field before and after harvest, respectively. The soil texture was determined with a Bouyoucos hydrometer, field capacity (FC, %) with a vacuum pump at 1/3 atmospheric pressure, and pH with a WTW Inolab 720 pH-meter in 1:2.5 soil-water suspension, organic carbon (C), total nitrogen (TN), available P, K, Cu, Mn, Zn and Fe with methods described in Kacar (2009).

Counts of Soil Bacteria and Fungi

Heterotrophic culturable total aerobic bacteria and fungi were determined by soil-dilution plate method on each sampling day. 0.1 g soil was placed in Eppendorf tubes containing 0.9 ml of 0.9% sterile sodium chloride and homogenized. After homogenization, serial tenfold dilutions of soil suspensions (10^{-3}) were plated in triplicate on plate count agar (PCA, Merck, Germany) for total aerobic bacteria count and on potato dextrose agar (PDA, Merck). 200 µg ml^{-1} Ampicillin (Sigma, Germany) was added to PDA medium to inhibit bacterial growth. The inoculated PCA and PDA plates were respectively incubated at 37°C for 1 day and at 28°C for 14 days before the colonies were counted (Atlas, 2005).

Carbon and Nitrogen Mineralization

Soil samples were placed in 750 ml incubation vessels for carbon mineralization. The final moisture contents of both soils were adjusted to 80% of their own field capacity before incubation at 28°C over 45 days. CO_2 derived from microbial activities was absorbed in 40 ml of saturated $Ba(OH)_2$ solution in beakers, placed in the center of the soils in closed incubation vessels, and then transferred to an incubator. The amount of CO_2 produced was measured once every 3 days by titration with oxalic acid. Empty vessels were used as blanks. The rate (%) of carbon mineralization was calculated through dividing the cumulative amount of carbon mineralization by soil organic carbon level (Kizildag et al., 2014). The kinetic parameters of carbon mineralization determined by a first-order exponential equation [($C_m=C_0$ $(1–e^{–kt})$] (C_m: cumulative carbon mineralized during t days, C_0: potentially mineralizable carbon, k: mineralization rate constant, C_0k: potential rate of initial carbon mineralization).

Nitrogen mineralization of the moisturized (80% of FC) soils was observed at 28°C for 45 days. Soil samples were shaken with 200 ml of 1 N $CaCl_2$ solution for 1 h. They were distilled to measure mineral nitrogen (NH_4 + NO_3) by the Parnas–Wagner method after filtering. In this study, mineral nitrogen amounts on beginning (1^{st} day) and end (45^{th} day) of incubation were divided by total nitrogen levels (Kacar, 2009; Kizildag et al., 2014).

Statistical Analysis

Tukey honestly significant difference (HSD) in Analysis of variance (ANOVA) was performed to determine the differences in soil chemical (element contents and pH) and biological properties (soil aerobic bacteria and fungi counts), carbon and nitrogen mineralizations between the 4 soils (Kleinbaum et al., 1998). All of the tests were performed at the significance level of P<0.05. Statistical analysis was carried out using the SPSS v20.

Results and Discussion

Some Physical and Chemical Properties of Soil

Some physical and chemical properties of soils were given in Table 1. Soils had 19.70% sand, 31.73% silt and 48.57% clay and soil textural class were named as clay. It was reported that clay contents in Lower Seyhan River Basin (Cukurova, Turkey) were in the range of 41.2–84.4% (Tuncay et al., 2016).

Soil pH was slightly alkaline and in the range of 7.98–8.18 and no significant differences were found among all soils. But Irmak and Vapur (2008) reported that soil pH in Cukurova region was ranged from 7.50–7.99. Field capacity of soils was in the range of 29.92–36.69% and was not changed significantly between control and sesame soils in each sampling period. However, both FC of soils were significantly increased after harvest (P<0.001).

Soil organic carbon (SOC) was ranged from 1.41–1.44% and there were not any significant differences between control and sesame field. Ortas (2013) and Ortas et al. (2017) reported that organic carbon of Menzilat soils at soil depth of 0-30 cm was found 0.87% in 2010 and 0.76% in 2013, respectively. Tuncay et al. (2016) reported that amounts of organic matter (OM) in Cukurova soils were in the range of 0.11–2.76%. Also, Irmak and Vapur (2008) found that OM in Cukurova soils was in the range of 1.46–2.33% that was similar in the SOC results of present study.

Total nitrogen (TN) was ranged from 0.11–0.12% and there were not any significant differences between control and sesame field. Sarı et al. (2002) and Ortas (2013) found that total nitrogen contents in Menzilat soils were 0.11% in 2002 and 0.17% in 2013, respectively.

Table 1 Some physical and chemical properties of soils

	Pre-Harvest		Post- Harvest		
Characteristics	Control	Sesame	Control	Sesame	P
Sand (%)	19.70 ± 0.06				-
Silt (%)	31.73 ± 0.03				-
Clay (%)	48.57 ± 0.03				-
Texture	Clay				-
pH	8.18 ± 0.06^a	8.18 ± 0.01^a	7.98 ± 0.06^a	8.09 ± 0.10^a	0.177
FC (%)	29.93 ± 0.04^a	29.92 ± 0.34^a	34.38 ± 0.67^b	36.69 ± 1.11^b	0.000
C (%)	1.44 ± 0.03^a	1.41 ± 0.01^a	1.44 ± 0.02^a	1.43 ± 0.05^a	0.909
N (%)	0.11 ± 0.00^a	0.12 ± 0.01^a	0.12 ± 0.00^a	0.11 ± 0.00^a	0.245
C:N	12.70 ± 0.37^a	12.09 ± 0.62^a	12.41 ± 0.71^a	13.42 ± 0.12^a	0.335
P_2O_5 (kg/da)	4.34 ± 0.16^c	4.53 ± 0.10^{bc}	4.94 ± 0.17^b	5.89 ± 0.07^a	0.000
K (ppm)	501.32 ± 7.04^b	599.00 ± 5.62^c	454.78 ± 5.60^a	480.50 ± 8.07^{ab}	0.000
Cu (ppm)	1.84 ± 0.02^a	1.60 ± 0.05^b	1.63 ± 0.01^b	1.40 ± 0.05^c	0.000
Zn (ppm)	1.46 ± 0.06^a	1.61 ± 0.09^a	1.67 ± 0.05^a	1.55 ± 0.13^a	0.423
Mn (ppm)	13.36 ± 0.05^a	12.59 ± 0.54^{ab}	12.63 ± 0.05^{ab}	10.99 ± 0.56^b	0.015
Fe (ppm)	8.49 ± 0.06^a	5.76 ± 0.24^c	7.26 ± 0.12^b	6.37 ± 0.44^{bc}	0.000

FC: Field capacity, mean ± standart error, n=3

Table 2 Parameters estimated according to the first-order exponential model for soil carbon mineralization

Sampling times	Cm	C_0	k	C_m/C_0
	(mg CO_2-C 100 g^{-1})		($days^{-1}$)	(%)
Pre_C	29.83[c]	38.56[c]	0.035[a]	77.37[a]
Pre_S	32.95[a]	42.03[ab]	0.036[a]	78.40[a]
$Post_C$	29.05[c]	41.52[bc]	0.028[b]	69.97[b]
$Post_S$	31.44[b]	45.04[a]	0.028[b]	69.80[b]

C_m: cumulative carbon mineralized during 45 days. C_0:potentially mineralizable carbon. k: mineralization rate constant

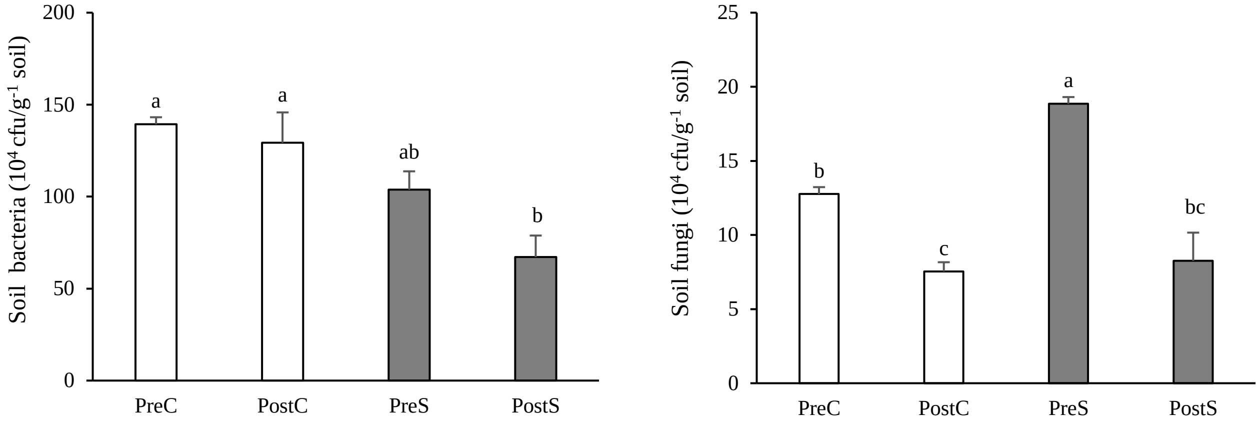

Figure 1 Soil aerobic bacteria and fungi counts in control and sesame soils before (Pre_C, Pre_S) and after ($Post_C$, $Post_S$) harvest. Different letters denote significant differences among 2 fields and 2 sampling times (P<0.05)

C:N was in the range of 12.09–13.42 and there were not any significant differences between control and sesame field. The ratio of C:N indicates the rate of decomposition of organic matter and this results in the release (mineralization) or immobilization of soil nitrogen (Swangjang, 2015). Valdez et al. (2017) indicated that nitrogen fertilizer significantly reduced SOC and total nitrogen stocks at depths greater than 15 cm in switchgrass cropping systems. On the other hand, Trost et al. (2014) found that combined effect of nitrogen fertilizer and irrigation enhanced carbon inputs from above ground harvest residues but these inputs didn't significantly affect organic carbon contents in sandy soil. They concluded that changes in above ground harvest residues C/N ratio and soil moisture caused by combination of irrigation and nitrogen fertilizer have improved microbial decomposition but these carbon inputs from residues were nullified. C, N and C/N contents in present study were similar in all soils.

Soil phosphorus contents (P_2O_5) were ranged from 4.34–5.89 kg da^{-1} in Menzilat soils. P_2O_5 contents were increased in all soils after harvest and there were found significant differences among sampling times (P<0.001). Sari et al. (2002) and Ortas (2013) reported that phosphorus contents in Menzilat soils were 27.8 and 8 kg da^{-1}, respectively. Korkmaz et al. (2010) indicated that when P fertilizer is added to such soils, it forms relatively insoluble aluminum (Al), iron (Fe), and calcium (Ca)–P complexes and, as a result, only a small proportion (10–30%) of the added P is taken up by the crop in the first year, with decreasing amounts in subsequent years, but much of the added P remains in the soil. Phosphorus does not have a gaseous phase like nitrogen and it's less mobile in the soil–plant–atmosphere system than nitrogen. One consequence of this lower phosphorus mobility throughout the soil profile is that when P fertilizers are applied, they tend to increase soil phosphorus concentration on the soil surface, but they also make phosphorus available by loss through the soil erosion process and surface runoff (Messiga et al., 2013). In present study, NPK fertilizer may have increased phosphorus content in sesame field after harvest. Irmak and Vapur (2008) reported that optimum amount of soil P_2O_5 content to provide growing condition for plants is about 8 kg da^{-1} and excess amount of utilizable phosphorus content seems to have a negative effect on other microelements uptake from soil.

K contents were similar in all soils and in the range of 454.78–599.00 ppm. Potassium contents in control and sesame field were higher before harvest than after harvest and there were found significant differences between sampling times (P<0.05). Sarı et al. (2002) and Ortas (2013) reported that potassium contents were 900 and 850 ppm at a soil depth of 0–20 cm of Menzilat series, respectively.

Soil Cu contents were in the range of 1.40–1.84 ppm and it was decreased in all soils after harvest. Significant differences were found between control and sesame field before and after harvest, separately (P<0.001). Soil Mn contents were in the range of 10.99–13.36 ppm and decreased in all soils after harvest (P<0.05). Cu and Mn contents in soils before harvest have decreased after harvest and significant differences were found between sampling times (P<0.05). Irmak (2009) found that Cu contents in soils of Cukurova were in the range of 0.78–1.56 ppm in 2005 and 1.12–1.96 ppm in 2006. Irmak and Vapur (2008) reported that manganese contents in Cukurova soils were in the range of 1.47–3.80 ppm that was lower than Mn results in present study.

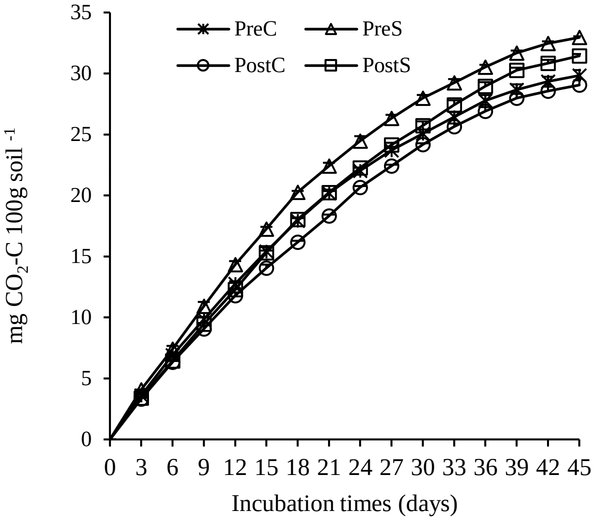

Figure 2 Cumulative carbon mineralized in control and sesame soils before (Pre_C and Pre_S) and after ($Post_C$ and $Post_S$) harvest (45 days, 28°C)

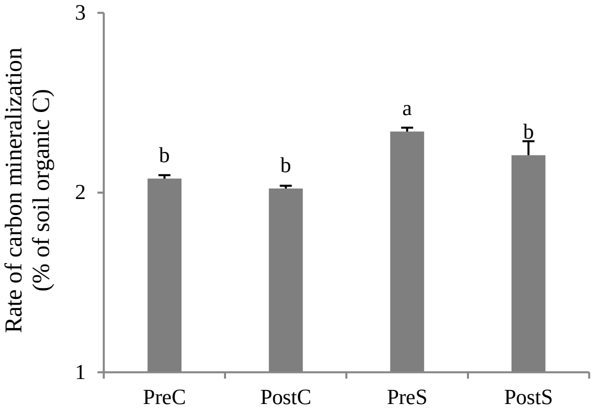

Figure 3 Rate of carbon mineralization in the control and sesame soils before and after harvest (45 days, 28°C). Different letters denote significant differences among 2 fields and 2 sampling times (P<0.05)

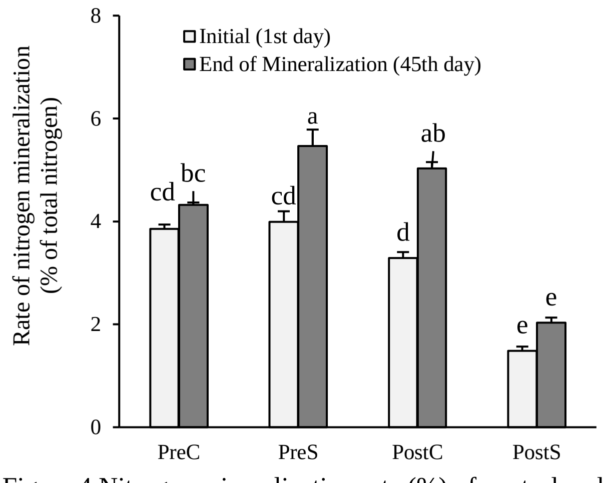

Figure 4 Nitrogen mineralization rate (%) of control and sesame soils on 1st and 45th days at 28°C. Different letters denote significant differences among 2 fields and 2 sampling times (P<0.05)

Amounts of soil Zn were in the range of 1.46–1.55 ppm and no significant differences were found between all soils in all harvest times. Irmak et al. (2008a) reported that zinc content of Cukurova soils was determined as low ranging from 0.16 to 1.10 ppm and suggested that application of zinc fertilizer is required to achieve intended yield gain in Cukurova region.

Soil Fe contents were in the range of 5.76–8.49 ppm and control was only significantly different with sesame field before harvest (P<0.001). Irmak et al. (2008b) reported that Fe contents of collected soils were ranged from 2.60–6.00 in 2005 and 6.96–12.70 ppm in 2006. Same authors indicated that critical Fe contents in soils were 4.5 ppm that is sufficient for Fe data in present study. Highest Zn and lowest Fe contents were determined in pre-harvest control while Zn contents have decreased but Fe contents have increased after harvest in sesame field but no significant differences were found among sampling times. Cakmak et al. (2010) reported that concentrations of Cu, Zn, Mn and Fe in Cukurova University Research Farm were 1.24, 0.49, 6.64 and 5.8 ppm. On the other hand, Ortas (2013) found that Cu, Zn, Mn and Fe contents of Menzilat soils in Cukurova University were 0.20, 0.30, 3.00 and 1.58 ppm.

In summary, soil carbon and nitrogen amounts in present study showed similarities with previous studies while phosphorus and potassium contents were lower in this study than previous findings. Generally, our results of micronutrients in present study were higher than previous studies.

Soil Aerobic Bacteria and Fungi Counts

In present study, bacteria were the most dominant microorganism and the fungi were the least. Soil aerobic bacteria and fungi populations were respectively higher and lower in control than sesame soils in all sampling periods (Figure 1). Control was only significantly different with sesame soil in bacteria populations before harvest and in fungi populations after harvest (P<0.05). In control and sesame soils, bacteria populations decreased by 7.8% and 35.3% while fungi populations decreased by 41.0% and 56.2% after harvest, respectively. Su et al. (2004) reported that soil culturable bacteria were ranged from 2.0×10^5 – 10.9×10^6 cfu g^{-1} soil in an arid environment of Northwest China. Ogunmwonyi et al. (2008) indicated that bacterial counts were in the order of 10^5-10^7 cfu g^{-1}, while fungal counts were in the order of 10^3–10^5 cfu g^{-1} soil in Obafemi Awolowo University.

Carbon and Nitrogen Mineralization

Cumulative carbon mineralization was 29.83 (Pre_C), 29.05 ($Post_C$), 32.95 (Pre_S), and 31.44 ($Post_S$) mg CO_2-C 100 g^{-1} soil after 45 days (Figure 2). There were only found significant differences between before and after harvest in carbon mineralization of sesame soils (P<0.05). As expected, agricultural practices increased carbon mineralization in this study. Soil CO_2 respiration has been widely used for many years to quantify the impact of various treatment and management inputs on soil microbial activity (Haney et al., 2008). Kizildag et al. (2014) reported that carbon and nitrogen contents were higher in no insecticide applied soil (NI) than an insecticide applied soil (I). Same authors incubated these soils moistured at their 80% of field capacity for 45 days at 20°C and there were found no differences between I and NI soils.

Rate of carbon mineralization (C_{min}) in sesame soils was higher than control before and after harvest (Figure 3). C_{min} rate of control and sesame soils decreased by 2.71% and 5.95% after harvest, respectively (Figure 3). There were only found significant differences between sesame soils before and after harvest ($P<0.05$).

The kinetics of C mineralization obtained from the first order kinetic model ($C_m = C_0(1 - e^{-kt})$ have been reported in Table 2. Potential mineralizable C (C_0) followed a same trend to C_m was in the range of 38.56–45.04 mg CO_2 -C 100 g^{-1} and k was decreased after harvest in all soils. It was found that in all soils, 77% of C_0 before harvest and 70% of C_0 after harvest have reached to C_m after 45 days. C_0 increased while potential rate of initial carbon mineralization was decreased in all soils after harvest.

N_{min} rates were higher on 45th day than 1st day in all soils and in all sampling times (Figure 4). On the other hand, N_{min} rate was higher before harvest while it was lower after harvest in sesame soils compared to control after 45 days of incubation. $Post_S$ had significantly lowest N_{min} rate compared to other applications ($P<0.05$). N_{min} rate was increased in control but it was significantly decreased in sesame soils after harvest at the end of incubation period ($P<0.01$).

Conclusions

In general, chemical and biological properties of soils in present study were changed after the four months harvest period. Differences in element contents between present study and previous studies could be based on different sampling times and locations in study area. N_{min} was lowest in $Post_S$ after 45 days of incubation compared to other parameters. Carbon mineralization was higher in sesame field than control before and after harvest and it decreased after harvest in all soils. Also, bacteria population in control was higher than sesame field while fungi population in sesame soils was higher than control in all sampling times. However, soil microorganisms were decreased after harvest. Decrease in carbon mineralization in all soils may be explained with decrease in soil microbial populations after harvest. However, this decrease may have enhanced potential mineralizable C.

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