Anadolu Tarım Bilim. Derg., 2012, 27(1):31-40
Anadolu J Agr Sci, 2012, 27(1):31-40
doi: 10.7161/anajas.2012.v27n1.3140
URL: http://dx.doi.org/10.7161/anajas.2012.v27n1.3140

**Research**
**Araştırma**

# EFFECT OF ALKALINE STABILIZED DOMESTIC WASTEWATER ON SOIL PROPERTIES AND YIELD, QUALITY AND NUTRITION OF SILAGE MAIZE

**Betül BÜRÜN[1] A. Levent TUNA[1*] İbrahim YOKAŞ[2] Hülya ÖZKUL[3]**

[1]Department of Biology, Faculty of Science, Muğla University, Muğla-Turkey
[2]Ortaca Vocational School, Muğla University, Muğla-Turkey
[3]Department of Feeds and Animal Nutrition, Faculty of Agriculture, Ege University, Izmir-Turkey
*tuna@mu.edu.tr

**Received Date: 15.02.2011 Accepted Date :14.12.2011**

**ABSTRACT:** Reuse of domestic wastewater that does not contain heavy metals or pathogenic microorganisms, as irrigation water is a significant method in terms of water conservation all around the world. In this field trial which was conducted over two years, the domestic wastewater (DW) of Muğla City after being alkaline stabilized was used to irrigate maize plant for silage and the interaction of soil and water was also controlled during the trial. Alkaline stabilized domestic wastewater (ASDW) was applied in four different doses as 150 ton $ha^{-1}$, 300 ton $ha^{-1}$, 450 ton $ha^{-1}$ and 600 ton $ha^{-1}$. During the vegetation stage, periodic physical observations were done and soil and plant samples were collected in order to evaluate the state of nutrition and effects of alkaline stabilized domestic wastewater. In the analysis, it was determined that pH and salt content of the soil didn't change and the contents of Ca and Mg elements increased. Chemical composition, in vitro metabolic energy values and pH of silage feedstuffs samples were investigated. In comparison with control, alkaline stabilized domestic wastewater treatment increased dry matter, crude protein, crude fat (as ether extract) and thus the metabolic energy (ME) content of feedstuffs. For silage yield, crude protein and metabolic energy, the best results were obtained with 600 ton $ha^{-1}$ application. According to the results, after alkaline stabilized domestic wastewater application to soil, which is a finite natural resource, soil was not negatively affected, and the quality and physiological features of maize for silage were affected affirmatively. In conclusion, alkaline stabilized domestic wastewater can be reused as a source of irrigation water and fertilizer for agricultural purposes.
**Key Words:** Alkaline stabilization, Domestic wastewater, Land application, Maize

# KİREÇLE STABİLİZE EDİLMİŞ KENTSEL ATIK SULARIN SİLAJLIK MISIRDA BESLENME, KALİTE VE VERİM İLE TOPRAK ÖZELLİKLERİ ÜZERİNE ETKİSİ

**ÖZET:** Ağır metal ve patojen mikroorganizma ihtiva etmeyen kentsel atık suların sulama suyu olarak kullanımı, su korunumu açısından tüm dünyada kullanılan önemli bir metottur. Muğla İlinde iki yıllık tarla denemesiyle kireçle stabilize edilmiş kentsel atık sular silajlık mısır bitkisinin sulanmasında kullanılmış ve deneme süresince toprak ve su etkileşimleri kontrol altında tutulmuştur. Atık su; 150 ton $ha^{-1}$, 300 ton $ha^{-1}$, 450 ton $ha^{-1}$ ve 600 ton $ha^{-1}$ olmak üzere 4 farklı dozda uygulanmıştır. Vejetasyon süresince uygulanan atık suların toprağa ve bitkiye olan etkisini değerlendirmek amacıyla periyodik olarak toprak ve bitki örnekleri toplanmış ve fiziksel gözlemler yapılmıştır. Analizler sonucunda toprağın pH ve EC değerlerinin değişmediği ancak Ca ve Mg kapsamlarının arttığı tespit edilmiştir. Silaj örneklerinin kimyasal kompozisyonu, in vitro metabolik enerji ve pH değerleri silaj öncesi ve sonrası ayrı ayrı olmak üzere değerlendirilmiş ve kontrol uygulamaları ile atık su uygulama grupları karşılaştırıldığında; kuru madde, ham protein, ham yağ ve metabolik enerji kapsamlarının arttığı belirlenmiştir. Silaj verimi, ham protein kapsamı ve metabolik enerji açısından en iyi sonuçlar 600 ton $ha^{-1}$ uygulamasıyla elde edilmiştir. Elde edilen sonuçlara göre; kıt bir kaynak olan toprağa kentsel atık su uygulamasından sonra toprağın olumsuz etkilenmediği, önemli bir endüstriyel bitki olan silajlık mısırın fizyolojik özellikleri ve kalitesinin olumlu yönde etkilendiği ve ayrıca kireçle stabilize edilmiş kentsel atık suların önemli bir gübre ve sulama suyu kaynağı olarak yeniden kullanılabileceği yargısına varılmıştır.
**Anahtar Sözcükler:** Alkali stabilizasyon, kentsel atık su, tarımsal uygulama, mısır

## 1. INTRODUCTION

Cities in developing countries are experiencing unparalleled growth and rapidly increasing water supply and sanitation coverage that will continue to release growing volumes of wastewater. In many developing countries, untreated or partially treated wastewater is used to irrigate the city's own food, fodder and green spaces (Scott et al., 2004)

The use of domestic wastewater in agriculture is a centuries-old practice that is receiving renewed attention with the increasing scarcity of freshwater resources in many arid and semiarid regions. Driven by rapid urbanization and growing wastewater volumes, wastewater is widely used as a low-cost alternative to conventional irrigation water; it supports livelihoods and generates considerable value in urban and peri-urban agriculture despite the health and environmental risks associated with this practice. The use of domestic wastewater in agriculture is a common practice for diverse reasons, not least of which are water scarcity, fertilizer value, and lack of an alternative source of water (Scott et al., 2002).

Application of wastewater to farmland allows for the nutrient content and soil amendment properties of these residuals to be used advantageously for sustained crop production (Jacobs and McCreary, 2001). Domestic wastewater may be a valuable source of N, P, essential trace elements, and organic matter that improves soil physical properties and plant nutrient status (Vazquez-Montiel et al., 1996; Magesan et al., 1999; Tamoutsidis et al., 2002).

There are many advantages in using domestic wastewater in agriculture and it can be seen as a combined strategy for: direct benefits; conservation of water, recycling of nutrients, thereby reducing the need for farmers to invest in chemical fertilizer and provision of a reliable water supply to farmers particularly in low-income dry areas. Indirect benefits; prevention of pollution of rivers, canals and other surface water that would otherwise be used for the disposal of the wastewater and the disposal of municipal wastewater in a low cost and hygienic way (Hoek van der et al., 2002).

Haruvy (1997) indicated that wastewater irrigation in the central area could maintain agriculture and reduce costs if were actually demanded by agriculture. Such irrigation should be monitored regularly and applied cautiously, in accordance with optimal irrigation-fertilization policies, to decrease leaching and in combination with other methods, to decrease salinity and other pollutants. Economic, agricultural and environmental aspects are important considerations in any decision-making regarding wastewater treatment and reuse options.

Jarausch-Wehrheim et al. (2001) indicated that sewage sludge could be a valuable source for a balanced nutrition supplement of maize that fits the new European Regulations. Sewage sludge or controlled waste water would be a valuable source for maize nutrition even after long-term application, if the critically high copper (Cu) and zinc (Zn) concentrations, previously reported in these sludge treated plants, could be avoided by the use of sludge with low concentrations of these elements (Fytili and Zabaniotou, 2008).

Sewage sludge or domestic wastewater has been already utilized in agricultural and horticultural applications for years, as it represents an alternative source of nutrients for plant growth and an efficient soil conditioner, enhancing certain physical properties of soil (US EPA, 1983, 1999; Samaras et al., 2008). Similarly agricultural reuse of wastewater offers an additional resource of irrigation water and high soil fertilizing potential (Russell et al., 1991; Kouraa et al., 2002).

Materials that may be used for alkaline stabilization include hydrated lime, quicklime (Calcium oxide), fly ash, lime, cement kiln dust and carbide lime (El-Naim et al., 2004). The alkaline-stabilized product is suitable for application in many situations, such as landscaping, agriculture and mine reclamation (Christensen, 1987; Bürün et al., 2006).

Lime is considered to be one of the most common amendment materials for sewage sludge or waste water alkaline stabilization, as it plays significant role in reducing the microbial content of sludge (pathogens), as well as the availability of heavy metals, enhancing the agricultural benefits and lowering the respective environmental risks. This process has been proposed for the advanced treatment of sewage sludge in the relevant EU working document on sludge usage. The high pH values of the lime-sludge mixture maintained for extended periods, result in the destruction of microbial communities and in the reduction of metal bioavailability (Wong and Selvam, 2006). There have been significant findings indicating that biosolids can increase crop yields when applied to agricultural areas. Wastewater that did not include toxic heavy metals increased the yield of maize and clover by regulating the soil fertility. Additionally, by use of treated wastewater for irrigation the problems such as wastewater disposal and lack of water availability in arid zones could be controlled. Furthermore, it is an important source of nutrients to poor fertility soils for crop (Jimenez-Cisneros, 1995).

Similarly, Melo et al. (2002) reported that sewage sludge increased soil organic matter, pH, extractable phosphorus (P), K, Ca, amylase and cellulose activity, especially at the rate 160 t $ha^{-1}$. Some of the plant nutrients contained in sewage sludge, mainly P did not show a tendency to move down through the soil column, an indication that sewage sludge should be incorporated into the soil to improve nutrient bioavailability. Similar results have also been reported on various plants regarding amending soils with biosolids (Gavi et al., 1997; Sonmez and Bozkurt, 2006).

Wastewater discharge has significantly increased in growing urban areas, yet the need for agricultural output is increased in many areas due to increasing world population (US EPA, 2000). In this study herein, we have aimed to reuse domestic wastewater that are rich in nutrients, but include no heavy metals and after alkaline stabilization, with the intent of increasing agricultural production. The goal of the study was two-fold, the use of non-toxic ASDW could be an important aspect of environmental recycling, and use of ASDW would be beneficial economically. A key concern in utilizing ASDW for use in the environment is also addressed herein in this study, where we have examined the effects of experimental usage on soil to ascertain or identify any potential negatives. ASDW was used with the aim of production of maize for silage, which has an important role in animal feeding in many area of the world.

## 2. MATERIALS AND METHODS

### 2.1. Characteristics of the Alkaline-stabilized Domestic Wastewater (ASDW)

Field experiments were conducted in the city center of Muğla, Turkey, during the years 2004 and 2005. Domestic wastewater (DW) was drawn off the cesspools, which is household waste disposal system of the houses in the city center of Muğla. The DW were investigated for whether reuse was possible for agricultural production after being altered with $Ca(OH)_2$ in a stabilization unit.

Four kg of $Ca(OH)_2$ per 1000 L of DW was combined and mixed together in an domestic wastewater stabilization unit (Muğla Municipality Domestic Wastewater Treatment Plant). The material [DW plus $Ca(OH)_2$] was maintained at pH 11-12 for 30 min and then poured into storage basins. After solid wastes precipitated to the bottom of the storage basin, the liquid wastes (wastewater) were removed by pipeline. The collected ASDW were then later transported by sewage truck (tank truck equipped with a suction pump, used for removing sewage from storage basin) to the application site.

The ASDW used as experimental material was analyzed with three months intervals for both experimental years (2004, 2005). The chemical analysis revealed mineral constituents of the ASDWs. Analysis was carried out by evaluating the presence of toxic metals (Cu, Pb, Co, Cd), to ensure that none were detected. Fe, Mn, and Cu were detected at a trace level (data not shown), and the ASDW were rich in N, K and Ca. Toxic (heavy) metals and micro and macro elements were analyzed by AAS (Atomic Absorption Spectrometry). The EC (Electrical conductivity) was 1.7 dS $m^{-1}$ and pH was 11.2. Properties of ASDW are also given in Table 1.

Table 1. Physicochemical properties (as mg $L^{-1}$) of alkaline stabilized domestic wastewater (ASDW)

| pH | EC dS $m^{-1}$ | Na | K | Ca | $NH_4^+$-N | $NO_3^-$ -N | B |
|---|---|---|---|---|---|---|---|
| 11.2 | 1.7 | 91 | 27 | 300 | 35.7 | 2.45 | 0.42 |

ASDW were tested for the presence of common pathogenic microorganisms (Anonymous 1995). A sample of 100 mL of the ASDW was tested for total coliform, fecal coliform, fecal streptococcus and *Staphylococcus aureus*, monthly. The levels detected were 0, for all pathogens tested. Furthermore, chemical oxygen demand, biochemical oxygen demand and total suspended solids decreased from 249 to 93; 130 to 13; 86 to 12 with the ASDW application rates, respectively (data not shown) (Klee 1991). In addition, the pH increased from 7.7 to 11.2.

### 2.2. Experimental Design and Treatments

The plant material tested was maize (*Zea mays* L.) cultivar DK647 grown in outdoor field conditions where experiments were carried out at Muğla City on the same field during two successive years (2004 and 2005). The experiments were established in a randomized block design, with three replications. In the experiments, each plot size was 16 m² and seeds were sowed in rows. Fertilizer composed of 210 kg N $ha^{-1}$, 80 kg $P_2O_5$ $ha^{-1}$ and 70 kg $K_2O$ $ha^{-1}$ was applied to the all plots as a basal dressing and adequately irrigated. ASDW was applied in four different doses as 150 ton $ha^{-1}$, 300 ton $ha^{-1}$, 450 ton $ha^{-1}$ and 600 ton $ha^{-1}$. In the control plots, 250 kg 15:15:15 of composed fertilizer $ha^{-1}$ was applied. The first waste application was done at the same time as seed sowing. A total of four applications were done at intervals of approximately 25 days and first plant and soil samples were collected after the second ASDW treatment.

### 2.3. Soil and Plant Sampling and Analytical Determinations

During the vegetation period, we conducted periodic physical observations and collected soil and plant samples in order to evaluate the state of nutrition and effects of the ASDW. Plant shoot length (cm), number of internodes, stem diameter, the seed yield for each plant and silage efficiency was determined.

We collected soil samples during the study, with depths from 0-30 cm of every plot before the ASDW application in soil. In soil samples, EC was determined by a 1:5 w/v soil/distilled water method; organic matter titrimetrically; macro and micronutrients (except total nitrogen) atomic absorption spectrometrically (Kacar, 2009). Total nitrogen was determined by the Kjeldahl method (Kacar, 2009).

### 2.4. Maize Silage Parameters and Applied Methods

At the end of the generative stage of maize, with the aim of making silage, all of the plant materials were broken into pieces by using a silage machine and were stored in a plastic covered silo. Silage samples taken from each plot were assessed in terms of a silage quality. In the first year before silage, roughage (crude feedstuffs) analysis and silage analysis for two periods was conducted. And in the second year silage quality analysis was carried out for one period.

With the aim of determining the effects of ASDW on the quality of maize silage, in the first year of collected feedstuffs prior to the silage chemical composition determination, dry matter (DM), crude ash (CA), crude protein (CP), crude fat (CF), crude fiber (CFi), pH and metabolic energy ME (kcal $kg^{-1}$) values were determined. In the first year for both of two periods that covered 45 days, in addition to the above mentioned analysis, cell wall contents of feedstuffs (neutral detergent fiber, NDF; acid detergent fiber, ADF) and silo acids (lactic acid, LA; acetic acid, AA and butyric acid, BA) were determined. All parameters analyzed in feedstuffs were analyzed as one period in the second year. Methods belonging to analyzed parameters are given below.

Chemical composition of the feedstuffs were analyzed by Weende and Lepper analysis methods Bulgurlu and Ergül, (1978), cell wall contents were analyzed by Van Soest detergent analysis method Goering and Van Soest, (1970) and silo acids were analyzed by a distillation method Naumann and Bassler, (1997). The pH values of silage samples were measured by using a digital pH-meter. While calculating in vitro ME values of feedstuffs, ME, the kcal $kg^{-1}$ = ‘‘3260 + (0.455×CP + 3.517×CF) – 4.037×CFi’’ regression equation was used (TSE, 1991). Samples for values of CP, CF and CFi were determined in 1 kg of organic matter.

**2.5. Statistical Analysis**

Data were analyzed for significance using one-way ANOVA and a compared means procedure with the SPSS v14 statistics program. Means were separated by LSD test $P < 0.05$ when F tests were significant at $P < 0.05$.

## 3. RESULTS

**3.1. Physical Observations and Yield of Maize**

In order to assess the effect of ASDW application on plant growth; shoot length (cm), number of internodes, diameter of second internodes (cm), seed yield and vegetative parts yielded for silage production (kg) are given in Tables 2 and 3. Data indicated that there was increase in plant height and stem diameter as a result of the ASDW application. When the shoot length control and highest ASDW dose were compared, the difference was 29% in the first year and 18% in the second year. For stem diameter, a similar increase was observed relatively speaking at the rates of 25 and 12%, in the first and second years, respectively. While on check plot plants one seeded corncob per each plant was observed. With increasing doses of waste application, plants were observed to be producing two corncobs for each plant and growths of small corncobs were observed. Silage yield was also positively affected by ASDW applications in the two years of the experiment. When control and the highest ASDW dose were compared, increases on yield were determined as 57% for the first year and 75% for the second year.

**3.2. Evaluation of Effects on Soil Properties of ASDW**

Domestic wastewater has been used in many countries as an input having agronomic value for a considerable time. Discharge of waste to soil has important considerations in terms of health of both the soil and impact on living organisms. For this reason in the study, all necessary soil parameters were periodically observed during discharge of ASDW with sensitivity. Before starting trials in the first year for one period and then, in the second year for three periods in growing season, elaborate soil analysis (depths from 0-30 cm) was carried out. Soil analysis results before trial are shown in Table 4. According to these results, all elements surveyed are above sufficiency levels.

Since the materials in use are stabilized with lime and they have a high pH value, it is very important to observe soil pH throughout the entire growing season. Thus, in the second year of the trial, soil samples were taken three times every 30 days and the effects of ASDW on soil were assessed (Table 5).

Soil pH was measured as 7.64 before the trial. The soil pH was determined for 600 ton $ha^{-1}$ on ASDW doses as 7.65 for the first period, 7.89 for the second period and 7.91 for the third period. The average pH over all three periods was 7.81. An increase of approximately 3% on soil pH can be seen as negligible, depending on the highest dose of ASDW application. The EC value also did not change before and after the experiments, yet the amount of organic matter declined. This decline was evident especially in the third period (the last period of the second year). Macro elements did not adopt any specific pattern. The amount of total N generally decreased; available K decreased slightly; available Ca did not change significantly; available Mg did not change in the first and second periods, yet increased just slightly in the third period; and, finally, available Na increased in every period measured. Micro elements also did not have any specific pattern. Available Fe decreased slightly in the first and second periods, yet increased slightly in the third period; available Cu decreased in every period measured; available Zn decreased slightly in every period; and, available Mn generally decreased in every period.

According to soil analysis performed in the first and second year, it was observed that soil pH and Fe, Cu and Mn elements did not change at a statistically significant rate. While content of organic matter and total N, K and Zn decreased, an increase in content of Ca, Mg and Na generally was observed (Table 5).

**3.3. Effects on Silage Maize Quality of ASDW**

Chemical composition of experimental feedstuff was quantified before ensiling, where in vitro metabolic energy and pH data are given in Table 6. As seen in Table 6, in comparison with control, as a result of treatment with ASDW there was an increase in dry matter, crude protein, crude fat and thus metabolic energy content of feedstuffs.

The chemical composition of the feedstuff, cell wall content, in vitro metabolic energy values, pH and quality criteria of silages gained in two different periods in the first year are described in Table 7. In the first period, in comparison with the control group, dry matter, crude protein, crude fat, crude fiber and metabolic energy content of silages increased markedly and especially in the group where the highest ASDW dose was applied, in comparison with both control and other groups and higher ME values were determined. Due to nutrition matter content in the second period for silages, dry matter content did not show an increase dependent on increasing the ASDW dose. The treatment of 450 ton $ha^{-1}$ containing the highest amount of dry matter, the ME value was observed to be the highest (Table 7). In the same table, it is noted that silages belonging to both of the periods increased markedly in comparison with the control, with regard to the crude fiber content. The NDF and ADF contents increased and gave the highest values especially for the first period in 600 ton $ha^{-1}$ and for the second period in 450 ton ha$^{-1}$ of the ASDW application.

In this study for both periods in control and all treatment groups, lactic acid was observed above 2%, acetic acid was observed below 0.8% and butyric acid was trace. In silages for the first period, the highest rate of lactic acid of 4.30% was attained from the ASDW application of 300 ton ha$^{-1}$, and a significant difference ($P < 0.05$) was found between the control and other groups. In the silages for the second period, rates of lactic acid in all treatment groups compared with control were found to be dramatically low, yet the closest rate of lactic acid compared to the control group was 2.61, gained from ASDW application of 150 ton ha$^{-1}$. The rate of acetic acid in silages for both periods was found dramatically low ($P < 0.05$) in all treatment groups, compared to the control, and lowest rate of acetic acid was gained from the ASDW application of 450 ton ha$^{-1}$. Butyric acid was found in trace quantities in silages for the first year.

The chemical composition of the feedstuffs, cell wall content, in vitro metabolic energy values, pH and silage quality criteria of silages gained in second year are provided in Table 8. As seen in Table 8, due to the chemical composition of silages, the content of dry matter, crude protein, crude fiber, NDF, ADF in all treatment groups increased in comparison with control group. At the level of 600 ton ha$^{-1}$ ASDW treatment, ME value had already increased to 17% of controls.

Table 2. Shoot length (cm) of maize plants at the first and second years

| | Treatments | Shoot length | | Treatments | Shoot length |
|---|---|---|---|---|---|
| 1st year | Control | 194 ± 7.1 d | 2nd year | Control | 166 ± 1.5 c |
| | 150 ton ha$^{-1}$ | 214 ± 9.9 c | | 150 ton ha$^{-1}$ | 176 ± 8.6 b |
| | 300 ton ha$^{-1}$ | 228 ± 4.5 cb | | 300 ton ha$^{-1}$ | 175 ± 4.1 b |
| | 450 ton ha$^{-1}$ | 237 ± 9.6 ba | | 450 ton ha$^{-1}$ | 201 ± 3.8 a |
| | 600 ton ha$^{-1}$ | 250 ± 13.2 a | | 600 ton ha$^{-1}$ | 196 ± 1.2 a |

Means and SD values with different letters in the same column are significant ($P < 0.05$) according to LSD multiple range test

Table 3. Internodium number, stem diameter (cm), corncob number and silage yield (kg plot$^{-1}$) of maize plants at the first and second year

| | Treatments | Internodium number | Stem diameter | Corncob number | Silage yield |
|---|---|---|---|---|---|
| 1st year | Control | 13.3 | 1.89 ± 0.18 d | 1 d | 60 ± 1.55 c |
| | 150 ton ha$^{-1}$ | 12.8 | 2.05 ± 0.11 dc | 1 d | 67 ± 10.0 b |
| | 300 ton ha$^{-1}$ | 12.6 | 2.12 ± 0.04 cb | 1.15 ± 0.015 c | 80 ± 5.0 b |
| | 450 ton ha$^{-1}$ | 12.3 | 2.26 ± 0.09 ba | 1.38 ± 0.015 a | 80 ± 2.0 b |
| | 600 ton ha$^{-1}$ | 12.6<br>ns. | 2.36 ± 0.02 a | 1.28 ± 0.030 b | 94 ± 4.20 a |
| 2nd year | Control | 11.5 | 1.01 | 1 | 80 ± 8 d |
| | 150 ton ha$^{-1}$ | 12.6 | 1.11 | 1 | 80 ± 6 d |
| | 300 ton ha$^{-1}$ | 12.7 | 1.08 | 1 | 100 ± 11 c |
| | 450 ton ha$^{-1}$ | 13.3 | 1.15 | 1 | 120 ± 10 b |
| | 600 ton ha$^{-1}$ | 12.5<br>ns. | 1.13<br>ns. | 1<br>ns. | 140 ± 12 a |

Means and SD values with different letters in the same column are significant ($P < 0.05$) according to LSD multiple ranges test. ns: non significant

Table 4. Some physicochemical properties of soil before the first year trial

| Parameters | pH | EC (dS m$^{-1}$) | Organic matter (%) | Total N (%) | K | Ca | Mg | Na | Fe | Cu | Zn | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Values** | 7.64 | 0.31 | 2.40 | 0.12 | 238 | 6180 | 149 | 10 | 7.5 | 2.2 | 3.8 | 8.2 |

Fe, Cu, Zn and Mn are available; K, Ca, Mg and Na are exchangeable (as mg kg$^{-1}$)

Table 5. Some physicochemical properties of soil before the first year and the second year trials (three periods average) as a result of ASDW treatments

| | Parameters | pH | Organic matter % | Total N % | K | Ca | Mg | Na | Fe | Cu | Zn | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before the trial | | 7.64 | 2.4a | 0.12 | 238ba | 6180dc | 149cb | 10d | 7.5 | 2.2 | 3.8a | 8.2 |
| Second year | Control | 7.80 | 2.1ba | 0.10 | 258a | 6920a | 190a | 26dc | 7.3 | 2 | 2.9dc | 6.6 |
| | 150 ton $ha^{-1}$ | 7.77 | 1.6b | 0.08 | 183c | 5933d | 144c | 40cb | 7.2 | 1.9 | 3.3cb | 5.9 |
| | 300 ton $ha^{-1}$ | 7.79 | 1.9b | 0.09 | 226ba | 6626ba | 169ba | 55cb | 7.7 | 2.1 | 3.1dc | 5.8 |
| | 450 ton $ha^{-1}$ | 7.76 | 1.6b | 0.07 | 200cb | 6446cb | 150cb | 100a | 6.5 | 1.8 | 2.8d | 6.4 |
| | 600 ton $ha^{-1}$ | 7.81 | 1.7b | 0.09 | 178c | 6120dc | 131c | 72ba | 7.3 | 2 | 3.5ba | 6.9 |
| | | ns | | ns | | | | | ns | ns | | ns |

Fe, Cu, Zn and Mn are available; K, Ca, Mg and Na are exchangeable (as mg $kg^{-1}$). Means with different letters in the same column are significant ($P < 0.05$) according to LSD multiple range test. ns: non significant

The pH values of silages did not show a significant difference ($P < 0.05$) between groups, and for this reason, it was determined that they were not affected dramatically by two-year-long ASDW applications. In silages during the second year, the highest rate of lactic acid with 4.05% was attained from ASDW application in 150 ton $ha^{-1}$, and significant differences ($P < 0.05$) were found between the control and other groups. The level of acetic acid in the control group was found to be a dramatically low ($P < 0.05$) and among treatment groups, where the highest rate was 0.62%, attained from ASDW application in 300 ton $ha^{-1}$. Rates of butyric acid were found at very low levels and similar in all treatment groups.

Table 6. Quality properties of crude feedstuffs before the silage

| Treatments | Dry matter (%) | Crude protein (%) | Ether extract (%) | Crude fiber (%) | Crude ash (%) | pH | Metabolic Energy (kcal $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| Control | 20.47d | 0.87d | 0.33b | 5.32b | 1.29ab | 3.82ab | 226d |
| 150 ton $ha^{-1}$ | 21.59c | 1.31c | 0.51a | 5.36b | 1.12b | 3.95a | 475c |
| 300 ton $ha^{-1}$ | 24.78a | 1.63b | 0.57a | 5.60a | 1.32a | 3.77ab | 566a |
| 450 ton $ha^{-1}$ | 24.96a | 1.88a | 0.52a | 5.76a | 1.19ab | 3.68b | 569a |
| 600 ton $ha^{-1}$ | 23.64b | 1.86a | 0.50ab | 5.37b | 1.30ab | 3.74ab | 538b |

Means with different letters in the same column are significant ($P < 0.05$) according to LSD multiple range test

Table 7. Results of silage quality analysis at the 1st and 2nd periods of the first year trial

| Treatment | D.M. (%) | Crude Protein (%) | Ether extract (%) | Crude fiber (%) | Crude ash (%) | pH | Meta-bolic Energy (kcal $kg^{-1}$) | ADF | NDF | Lactic acid | Acetic acid | Butyric acid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **1st period** | | | | | | | |
| Control | 23.3b | 1.23 c | 0.33 b | 5.15 c | 1.33 | 3.85 | 526 c | 6.66c | 12.35b | 3.13 b | 0.77 a | 0.02 |
| 150 ton $ha^{-1}$ | 24.5ab | 1.99 ab | 0.38 ab | 5.24 c | 1.28 | 3.65 | 569 b | 6.7bc | 13.34ab | 2.71bc | 0.68 ab | 0 |
| 300 ton $ha^{-1}$ | 26.5ab | 1.94 b | 0.13 c | 5.31 bc | 1.32 | 3.81 | 621 a | 6.8bc | 12.56 b | 4.30 a | 0.55 bc | 0 |
| 450 ton $ha^{-1}$ | 23.7ab | 1.82 b | 0.46 ab | 5.58 a | 1.22 | 3.80 | 532 c | 6.9b | 13.35ab | 2.03 c | 0.41 c | 0 |
| 600 ton $ha^{-1}$ | 27.1a | 2.25 a | 0.54 a | 5.54 ab | 1.34 ns | 3.84 ns | 648 a | 7.57a | 13.90 a | 2.08 c | 0.59abc | 0 ns |
| | | | | | **2nd period** | | | | | | | |
| Control | 22.1c | 1.77 ab | 0.30 ab | 4.78 bc | 1.29 a | 3.75 | 505 b | 5.9d | 10.26 c | 3.21 a | 0.73 a | 0 |
| 150 ton $ha^{-1}$ | 22.3bc | 1.64 b | 0.44 ab | 4.69 c | 1.19abc | 3.71 | 524 b | 6.27c | 10.43bc | 2.61 b | 0.48 b | 0 |
| 300 ton $ha^{-1}$ | 20.4d | 1.08 c | 0.48 a | 4.92 bc | 1.01 c | 3.73 | 456 c | 6.1dc | 10.95bc | 2.17bc | 0.48 b | 0.04 |
| 450 ton $ha^{-1}$ | 24.3a | 1.95 a | 0.37 ab | 5.52 a | 1.04 bc | 3.65 | 558 a | 7.37a | 13.47 a | 2.08 c | 0.41 b | 0 |
| 600 ton $ha^{-1}$ | 23.1b | 1.91 a | 0.25b | 5.01 b | 1.21 ab | 3.70 ns | 530 b | 6.7b | 11.31 b | 2.58 b | 0.52 b | 0 ns |

Dry matter (DM), Acid detergent fiber (ADF), Neutral detergent fiber (NDF)
Means with different letters in the same column are significant ($P < 0.05$) according to LSD multiple range test

Table 8. Results of silage quality analysis at the second year trials

| Treatment | D.M. (%) | Crude Protein (%) | Ether extract (%) | Crude fiber (%) | Crude ash (%) | pH | Metabolic Energy (kcal $kg^{-1}$) | ADF | NDF | Lactic acid | Acetic acid | Butyric acid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 30.10d | 1.77 d | 0.84 a | 5.52 c | 3.14 a | 4.12 | 694 b | 7.87bc | 14.72b | 3.56 b | 0.41 c | 0.01 c |
| 150 ton $ha^{-1}$ | 33.67b | 2.42 bc | 0.70 ab | 6.50ab | 2.62 b | 4.06 | 785 ab | 8.69ab | 14.96b | 4.05 a | 0.56ab | 0.01 c |
| 300 ton $ha^{-1}$ | 30.14d | 2.38 c | 0.60 b | 5.47 c | 2.12 c | 4.06 | 725 ab | 7.51 c | 13.59c | 3.87 a | 0.62 a | 0.02 b |
| 450 ton $ha^{-1}$ | 32.30c | 2.69 ab | 0.68 ab | 6.12bc | 2.33bc | 3.96 | 766 ab | 8 .80 a | 15.98a | 3.56 b | 0.51 b | 0.04 a |
| 600 ton $ha^{-1}$ | 35.01a | 2.96 a | 0.75 ab | 7. 28 a | 2.25bc | 4.07 ns | 813 a | 8 .91 a | 16.39a | 3.65 b | 0.52 b | 0.01 c |

Dry matter (DM), Acid detergent fiber (ADF), Neutral detergent fiber (NDF)
Means with different letters in the same column are significant (P < 0.05) according to LSD multiple range test

## 4. DISCUSSION

Research and experience have shown that domestic wastewater or biosolids can be beneficial both as soil conditioners and as a source of nutrients (Rosenqvist et al., 1997; Faruqui et al., 2002; Tamoutsidis et al., 2002). When biosolids are stabilized by high lime treatment, they can also have some value as a liming material for acidic soils and can substitute for agricultural lime (Jacobs and McCreary, 2001; El-Naim et al., 2004). One study, which encouraged lime treatment, was reported by El-Naim et al. (2004). According to their study, lime application resulted in an increase in the pH values and temperature. The maximal values of temperature and pH were obtained when sludge was treated with 20% lime. No major differences were observed between the sludge treatments receiving lime at rates of 10, 15 and 20% lime. The 10% limed sludge treatment was the best for reducing concentrations of heavy metals and numbers of bacterial pathogens in sludge.

It is known that the use of biosolids as a fertilizer and as an amendment of soil physico-chemical properties is a common and sound environmentally practice. Christie et al. (2001) in a study on barley compared alkaline biosolids and the nutritious value of fertilizer. Alkaline biosolids increased the yield of barley plants and macro-element contents of leaves in two different types of soil at a significant rate according to controls. In this study, it was deduced that alkaline biosolid was an effective lime source and fertilizer material. Parallel to results gained from the studies above, the K, Ca and Mg contents of soil were also increased comparable to the first year data collected in our study.

Numerous researchers have demonstrated the beneficial effects of using wastewater or biosolids in agronomic applications. It has been shown that sewage sludge application improves the physical, chemical and biological properties of soil (Parr and Hornick, 1992; White et al., 1997; Aggelides and Londra, 2000; Benitez et al., 2001; Tamoutsidis et al., 2002). Reed et al. (1991) also reported that the fertilizer value of sludge was comparable to that of commercial fertilizers. It was reported in another study that soil productivity could be increased by reusing wastewater (Jimenez-Cisneros, 1995). Also in this study, applied ASDW did not change pH and salt content of the soil, and it positively influenced the quality and nutritional status of silage maize. Similar results were obtained by researchers in other studies (Jarausch-Wehrheim et al., 2001; Melo et al., 2002). Moreover, according to the study of Tamoutsidis et al. (2002), sewage sludge application increased soil organic matter content and soil concentrations of N, P, K, Ca and Mg. Increased macronutrients concentrations in soil-sewage sludge mixtures did not cause toxicity symptoms. Soils treated with sewage sludge were enriched in available Cu and Zn, accompanied with plant tissues enrichment for those micronutrients. These concentrations were similar to their sufficiency levels. Generally, wastewater or sewage sludge application resulted in increased yield in leaves or roots, without any plant deficiency symptoms. Consequently, their results showed that wet sewage sludge could be used for agricultural purposes in order to amend soil properties and as a full or partial substitute of conventional fertilizers. Our results also confirmed those findings.

In addition, according to Sonmez and Bozkurt, (2006) liquid biosolids applications increased organic matter, electrical conductivity, total N, available P, exchangeable K, total Cu, extractable Mn, Cu and Cd concentrations of topsoil. Extractable Fe, Cr and Zn and the total Cd, Cr and Zn increased in soil with added sludge. Soil pH was unaffected by sludge applications. It may be concluded that sewage sludge can enrich organic matter and rectify N, P, Fe and Zn deficiencies with high pH and calcareous soils.

In the present study, pH and EC being important criteria of soil fertility weren't affected significantly by ASDW treatments for two years. Buffering capacity of soil and rainfall are each determinational factor on this situation. In addition, the decrease observed on contents of some macro and microelements may be a result of high Ca content in the soil. Antagonism known between microelements and Ca may explain this situation.

Castro et al. (2009) studied the fresh and dry weight of lettuce (*Lactuca sativa* L.) after fertilization and irrigation with treated wastewater. According to the results, an increase in fresh and dry weight in the lettuce was linked to the dosage of sewage sludge. No significant changes in soil pH were observed. Significant increases in organic matter, P, K and Cu in the municipal solid waste with composted sludge were observed. Also in our study, even with the high doses of ASDW applications, soil pH did not change appreciably, but shoot length increased at the important rates especially in the first year.

Alkaline-stabilized sewage sludge can be used as a successful soil organizer and in providing nutritional matter in especially acid-reacted soil due to the lime it contains. Su and Wong, (2002) in a trial they carried out by using a similar material and with maize, reported that in soil, while soluble contents of Ca, Mg and B increased, content of $NH_4$-N, P, K, Cd and Ni decreased. In the same trial, it was indicated that dry matter content of maize plants also increased in comparison to controls. The increase of Ca and Mg contents described by Su and Wong, (2002) is similar with our study results herein.

Positive developments in yield, dry matter, and mineral nutrition parameters in many plants with biosolids application have been reported by different researchers (Bilgin et al., 2002; Bürün et al., 2006), with data similar to our findings. Biosolids applications with agricultural goals have had a significant economic benefit in terms of recycling of water and fertilizer (Ibrahim et al., 1995; Akrivos and Mamais., 2000). In many plants, nutritional output, which is ordinarily provided by fertilizing, can be obtained by biosolids applications. According to Al-Lahham et al. (2003) since treated wastewater has a high nutritive value that may improve plant growth, reduce fertilizer application rates and increase productivity of poor fertility soils, it is suggested that treated wastewater can be used to irrigate tomatoes that are eaten cooked, with a continuous monitoring of the effluent quality from the treatment plant to avoid contamination.

Nutrients contained in sludge increase plant biomass and yield. Furthermore, this material can be an important source of nutrients for the soil (Pedreno et al., 1996; Snyman et al., 1998; Cogger et al., 2001; Mena et al., 2003). Bozkurt and Yarılgaç, (2003) also reported that with sewage sludge application in apple trees, fruit yield, cumulative yield efficiency, shoot growth and the N, Mg, Fe, Mn and Zn content of its leaves increased significantly. In addition, Correa et al. (2005) also reported that biosolids have been reported to increase yields and supply plant nutrients in ryegrass (*Lolium* sp.). Evaluation with regard to silage yield, at the successive two years between silage yield and increased rates of ASDW application was found as a positive correlation in our study. The amount of dry matter of maize plants increased in comparison to control in a trial that Su and Wong, (2002) performed by using similar materials and maize. These studies support the idea that biosolids and similar applications can cause increase yield and quality properties many plants, depending on nutrition.

In the present study, it was determined that there was not a significant difference ($P < 0.05$) in the pH value, a silage quality criteria, in silages for the first year first period, and in silages for all doses for the second period in comparison with the control, except for ASDW application of 150 ton $ha^1$ (Table 7). It is known that in qualified silage, while lactic acid is required to be above 2%, acetic acid is required to be at a maximum 0.8% and butyric acid is not required (Kılıç, 1986).

## 5. CONCLUSION

This study was planned to examine the reuse of finite water resources. The application in agricultural areas and reuse of Muğla City domestic wastewater that does not contain heavy metal and pathogenic microorganisms as irrigation water and fertilizer source was investigated. The results show that domestic wastewater treatments did not damage soil, another finite resource. The quality and some physiological properties of maize for silage, an important industrial plant, were positively affected. In conclusion, ASDW that does not contain heavy metal and toxic matter can be reused as a source of irrigation water and fertilizer.

## 6. ACKNOWLEDGMENTS

The authors would like to thank Öztüre Holding, employees of the Muğla Lime Industry, Adnan Akyarlı (PhD.), Mesut Gerçek (MSc.), Ömer Özer, who is retired from Muğla Lime Industry for their financial and technical support and Asım Kılıç (PhD.), staff at the Department of Animal Science, Faculty of Agriculture at Ege University for his invaluable help and technical support. Thanks are due to Katherine, of Edit Avenue editing services, USA, for her assistance in the language editing of the manuscript.

## 7. REFERENCES

Aggelides, S.M. and Londra, P.A., 2000. Effect of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. Bioresource Technol. 71:253-259. doi:10.1016/S0960-8524(99)00074-7

Akrivos, J. and Mamais, D., 2000. Agricultural utilization of lime treated sewage sludge. Water Sci. and Technol. 42:9,203-210. http://www.iwaponline.com/wst/04209/wst042090203.htm

Al-Lahham, O., El Assi, N.M. and Fayyad, M., 2003. Impact of treated wastewater irrigation on quality attributes and contamination of tomato fruit. Agric. Water Manage., 61:51-62. doi:10.1016/S0378-3774(02)00173-7

Anonymous., 1995. Standard Methods for the Examination of Water and Wastewater, American Public Health Assocation, APHA, Washington.

Benitez, E., Romero, M., Gomez, M., Gallardo-Lara, F. and Nogales, R., 2001. Biosolid and biosolid ash as sources of heavy metals in plant-soil system. Water Air and Soil Pollut., 132:75-87. doi: 10.1023/A:1012012924151

Bilgin, N., Eyüpoğlu, H. and Üstün, H., 2002. Biyokatıların arazide kullanımı. Ankara Su ve Kanalizasyon İdaresi

Gen. Müd. ve Köy Hizm.Gen.Müd. ortak projesi. Ankara.

Bozkurt, M.A. and Yarilgac, T., 2003. The effects of sewage sludge applications on the yield, growth, nutrition and heavy metal accumulation in apple trees growing in dry conditions. Turk. J. Agric. For., 27:285-292. http://mistug.tubitak.gov.tr/bdyim/abs.php?dergi=tar&rak=0303-13

Bulgurlu, Ş. and Ergül, M., 1978. Yemlerin Fiziksel, Kimyasal ve Biyolojik Analiz Metotları. E.Ü.Z.F Yayınları, No: 127, İzmir.

Bürün, B., Tuna, A.L., Yokaş, İ. and Ege, H., 2006. Some soil properties of lime stabilized urban wastewater and effects on barley's yield and mineral matter content. J. of Agron., 5:1, 37-44. doi: 10.3923/ja.2006.37.44

Castro, E., Manas, M.P. and De Las Heras, J., 2009. Nitrate content of lettuce (*Lactuca sativa* L.) after fertilization with sewage sludge and irrigation with treated wastewater. Food Additiv. and Contamin., 26: 2, 172-179. doi: 10.1080/02652030802425334

Christie, P.D., Easson, D.L., Picton, J.R. and Love Stanley, C.P., 2001. Agronomic value of alkaline-stabilized sewage biosolids for spring barley. Agron. J., 93:144-151. doi:10.2134/agronj2001.931144x

Christensen, G.L., 1987. Lime stabilization of wastewater sludge. In: Lime for environmental use in ASTM-STP 931. (Ed. K.A Gutschick), American Society for Testing and Materials, Philadelphia, pp.78-94. ISBN: 0-8031-0499-5

Cogger, C.G., Bary, A.I., Fransen, S.C. and Sullivan, D.M., 2001. Seven years of biosolids versus inorganic nitrogen applications to tall fescue. J. Environ. Qual., 30: 2188-2194. doi:10.2134/jeq2001.2188

Correa, R.S., White, R.E. and Weatherley, A.J., 2005. Biosolids effectiveness to yield ryegrass based on their nitrogen content. Scientia Agricola (Piracicaba, Braz.) 62:3, 274-280. doi: 10.1590/S0103-90162005000300011

El-Naim, M.A., El-Housseini, M. and Naeem, M.H., 2004. Safety use of sewage sludge as soil conditioner. J of Environ. Sci. and Health Part A., 39:2, 435-444. doi: 10.1081/ESE-120027534

Faruqui, N.I., Niang, S. and Redwood, M., 2002. Untreated wastewater use in market gardens: A Case Study of Dakar, Senegal, IWMI; Int. Water manage. Ins. Research Report: 63. http://www.idrc.ca/awards/ev-68338-201-1-DO_TOPIC.html

Fytili, D. and Zabaniotou, A., 2008. Utilization of sewage sludge in EU application of old and new methods- A review. Renewable and Sustainable Energy Reviews 12:116-140. ISBN 92-5-103013-8

Gavi, F., Raun, W.R., Basta, N.T. and Johnson, G.V., 1997. Effect of sewage sludge and ammonium nitrate on wheat yield and soil profile inorganic nitrogen accumulation. J. of Plant Nutr., 20:2, 203-218. doi: 10.1080/01904169709365244

Goering, H.K. and Van Soest, P.J., 1970. Forage Fiber Analyses. Agric. Handbook No:379, Wash. D.C., p.829. ID Numbers, open library: OL13933073M

Haruvy, N., 1997. Agricultural reuse of wastewater: nation-wide cost-benefit analysis. Agric. Ecosyst. Environ., 66:113-119. doi: 10.1016/S0167-8809(97)00046-7

Hoek van der, W., Hassan, M.U., Ensink, J.H.J., Feenstra, S., Sally, L.R., Munir, S., Alsam, R., Ali, N., Hussain, R. and Matsuno, Y., 2002. Urban wastewater: A valuable resource for agriculture, A case study from Haroonabad, Pakistan, IWMI; Int. Water manage. Ins. Research Report: 63. ISBN: 92-9090- 504-2

Ibrahim, M., Ahmad, N. and Khan, A., 1995. Use of city wastewater for vegetable production. Proceedings. Soil fertility and fertilizer management 9th int. symp. of CIEC, 25-30 Sept. Kuşadası-Turkey.

Jacobs, L.W. and McCreary, D.S., 2001. Utilizing biosolids on agricultural land. Extension Bulletin, E 2781. Michigan State University Extension, USA. https://www.msu.edu/~warncke/E2781%20Utilizing%20Biosolids%20on%20Agricultural%20Land.pdf

Jarausch-Wehrheim, B., Mocquot, B. and and Mench, M., 2001. Effect of long-term sewage sludge applicatıon on the distribution of nutrients in maize (*Zea mays* L.). J. Plant Nutr., 24:9, 1347-1365. http://cat.inist.fr/?aModele=afficheN&cpsidt=14361869

Jimenez-Cisneros, B., 1995. Wastewater reuses to increase soil productivity.Water Sci. Technol. 32:12, 173-180. http://www.iwaponline.com/wst/03212/wst032120173.htm

Kacar, B., 2009. Toprak analizleri (Soil Analysis Methods), Second Revised and Re-edited version, Nobel Yayın Dağıtım, no: 1387, Fen Bil: 90, Ankara.

Kılıç, A., 1986. Silo yemi (Silage feedstuffs). Bilgehan basımevi, İzmir.

Klee, O., 1991. Angewandte Hydrobiologie G. Theieme Verlag, 2. neubearbeitete und erweiterte, Auflage, Stuttgart-New York.

Kouraa, A., Fethi, F., Fahde, A., Lahlou, A. and Ouazzani, N., 2002. Reuse of urban wastewater treated by a combined stabilisation pond system in Benslimane (Morocco) Urban Water, 4:373-378. doi: 10.1016/S1462-0758(01)00067-X

Magesan, G.N., Williamson, J.C., Sparling, G.P., Schipper, L.A. and Lloyd-Jones, A.R., 1999. Hydraulic conductivity in soils irrigated with wastewaters of differing strengths: Field and laboratory studies, Aust. J. Soil Res., 37: 391-402. doi:10.1071/S98030

Melo, W.J., Marques, M.O., Ferreira, M.E., Melo, G.M.P. and Melo, V.P., 2002. Chemical properties and enzyme activity in a sewage sludge-treated soil. Commun. Soil Sci. and Plant Anal., 33:9, 1643- 1659. http://cat.inist.fr/?aModele=afficheN&cpsidt=13679231

Mena, E., Garrido, A., Hernandez, T. and Garcia, C., 2003. Bioremediation of sewage sludge by composting. Commun. Soil Sci. Plant Anal., 34:957-971. doi: 10.1081/CSS-120019102

Naumann, C. and Bassler, R., 1997. Die chemische untersuchung von Futtermitteln. Methodenbuch, Band III. VDLUFA-Verlag, Darmstadt.

Parr, J.F. and Hornick, S.B., 1992. Utilization of municipal wastes. In: Soil Microbial Ecology: Applications in Agricultural and Environmental Management. (Ed. FB Metting) pp. 545-559. Marcel Dekker. NY. ISBN: 0-8247-8737-4

Pedreno, J.N., Gomez, I., Moral, R. and Mataix, J., 1996. Improving the agricultural value of a semi arid soil by addition of sewage sludge and almond residue. Agric. Ecosyst. and Environ., 58:115-119. doi: 10.1016/0167-8809(95)01005-X

Reed, B.E., Carriere, P.E., Matsumoto, M.R., 1991. Applying sludge on agricultural land. Biocycle 37: 58-60.

Rosenqvist, H., Aronsson, P., Hasselgren, K. and Perttu, K., 1997. Economics of using municipal wastewater irrigation of willow coppice crops. Biomass and

Bioenergy, 12:1, 1-8. doi:10.1016/S0961-9534(96) 00058-X

Russell, J.M., Cooper, R.N. and Lindsey, S.B., 1991. Reuse of wastewater from meat proc. plants for agricultural and forestry irrigation. Water Sci. Technol., 24:9, 277-286. http://md1.csa.com/partners/viewrecord.php?requester= gs&collection=TRD&recid=20070650353501MT

Scott, C.A., Faruqui, N.I. and Raschid-Sally, L., 2002. Coordinating the livelihood and environmental realities. In: Wastewater use in irrigated agriculture: Management Challenges in Developing Countries. (Eds. Scott C.A, Faruqui N.I, Raschid-Sally L) pp. 1-11. CAB International in association with the International Water Management Institute and International Development Research Centre. http://www.idrc.ca/openebooks/112-4/

Scott, C.A., Faruqui, N.I. and Raschid-Sally, L., 2004. Wastewater use in irrigated agriculture, Confronting the Livelihood and Environmental Realities. CABI, IWMI, IDRC / 2004-01-01, 0-85199-823-2, 1-55250-112-4.

Samaras, P., Papadimitriou, C.A., Haritou, I. and Zouboulis, A.I., 2008. Investigation of sewage sludge stabilization potential by the addition of fly ash and lime. J. of Hazardous Material., 154:1052-1059. doi:10.1016 /j.jhazmat.2007.11.012

Snyman, H.G., De Jong, J.M. and Aveling, A.S., 1998. The stabilization of sewage sludge applied to agricultural land and the effects on maize seedlings. Water Sci. Technol., 38: 87-95. doi:10.1016/S0273-1223(98)00 477-6

Sonmez, F. and Bozkurt, M.A., 2006. Lettuce grown on calcareous soils benefit from sewage sludge. Acta Agric. Scandinavica Section B-Soil and Plant Sci., 56:17-24. doi: 10.1080/09064710510005813

Su, D.C. and Wong, J.W.C., 2002. The growth of corn seedlings in alkaline coal fly ash stabilized sewage sludge. Water Air and Soil Pollut., 133: 1-13. doi: 10.1023/A:1012998530689

Tamoutsidis, E., Papadopoulos, I., Tokatlidis, I., Zotis, S. and Mavropoulos, T., 2002. Wet sewage sludge application effect on soil properties and element content of leaf and root vegetables. J. of Plant Nutr., 25:9, 1941-1955. doi: 10.1081/PLN-120013286

Türk Standartları Enstitüsü (T.S.E.) 1991. Hayvan yemleri-metabolik enerji tayini-kimyasal metot. (Animal feeds-Metabolic energy determination-chemical methods), TS 9610 Ankara.

US.EPA., 1983. Process design manual for land application of municipal sludge. Office of research and development municipal environmental research laboratory. No: 625/1-83-016. U.S. Environmental Protection Agency, Washington DC. http://yosemite.epa.gov/water/ owrc catalog.nsf/e673c95b11602f2385256ae1007279fe/69bef 6cae57de23085256b060072489f!OpenDocument

US.EPA., 1999. Biosolids generation, use, and disposal in the United States. EPA 530-R-99-009. Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington DC, 86 pages.
http://yosemite.epa.gov/water/owrccatalog.nsf/7322259e90d 060c885256f0a0055db68/43378ced9f51c48585256db20 05203af!OpenDocument

US.EPA., 2000. Guide to field storage of biosolids and other organic by-products used in agriculture and for soil resource management. Environmental Protection Management Agency (4204). United States Office of Wastewater, EPA/832-B-00-007, 136 pages. http://water.epa.gov/scitech/wastetech/biosolids/

Vazquez-Montiel, O., Horan, N.J. and Mara, D.D., 1996. Management of domestic wastewater for reuse in irrigation. Water Sci. Technol., 33:10-11, 355-362. http://www.iwaponline.com/wst/03310/wst033100355.htm

White, C.S., Loftin, S.R. and Aguilar, R., 1997. Application of biosolid to degraded semiarid rangeland: Nine-year responses. J Environ Qual 26: 1663-1671. http://cat.inist.fr/?aModele=afficheN&cpsidt=2179421

Wong, J.W.C. and Selvam, A., 2006. Speciation of heavy metals during co-composting of sewage sludge with lime. Chemosphere, 63:980-986. doi:10.1016/ j.chemosphere.2005.08.045