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A Preliminary Study on Response of Iron Content and Yield of Corn to Different Rates of Sewage Sludge

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ABSTRACT: *The treated sludge can be applied to arable soils if they do not contain heavy metals and toxic substances. This preliminary study was carried out in order to investigate the effects of application of treated sludge and Fe fertilizer on the yield and Fe content of maize. The trial was conducted in randomized plots design with three replications as pot experiment and C-955 hybrid maize was grown for silage. As basic fertilization, 200 mg kg^{-1} N, 100 mg kg^{-1} P and 150 mg kg^{-1} K were applied to all of the pots. Treatments were (C) control, (T1) 5 mg kg^{-1}Fe (Fe in sludge) + 10 mg kg^{-1}Fe ($FeSO_4$,$7H_2O$), (T2) 10 mg kg^{-1} Fe (Fe in sludge) + 5 mg kg^{-1} Fe ($FeSO_4$,$7H_2O$), (T3) 15 mg kg^{-1} Fe (Fe in sludge) and (T4) 15 mg kg^{-1} Fe ($FeSO_4$,$7H_2O$). Applications of sludge and Fe increased wet weight, dry weight, plant height, leaf number and the content of N, K, Fe, Zn and Cu of maize plant. It was concluded that application of 15 mg kg^{-1} Fe in sludge is sufficient for Fe need of maize. However, the obtained results from this study were valid only for this study soil and sewage sludge and should be used without generalization as they can vary under different conditions such as soil and climate. Therefore, further researches are needed on this field.*

Keywords: *Maize, iron, treated sludge, yield.*

Mısır Bitkisinin Demir İçeriği ve Veriminin Farklı Dozlarda Atık Su Çamuru Uygulamasına Tepkisi Üzerine Bir Ön Çalışma

ÖZ: *Arıtma çamurlarının tehlikeli ağır metaller ve toksik maddeler içermemesi durumunda, topraklarda kullanılabilirliği mümkündür. Bu ön çalışmada mısır bitkisine arıtma çamuru ile birlikte uygulanan demirli gübrelemenin bu bitkinin verim ve bitki besin elementi içeriği üzerine olan etkisi belirlenmeye çalışılmıştır. Araştırma saksı denemesi olarak 3 tekrarlamalı olarak tesadüf parselleri deneme desenine göre yürütülmüş ve saksılarda C-955 silajlık hibrit mısır çeşidi yetiştirilmiştir. Denemede saksılara temel gübreleme sabit dozda 200 mg kg^{-1} N, 100 mg kg^{-1} P ve 150 mg kg^{-1} K olarak uygulanmıştır. Deneme konuları olarak; (K) % 100 toprak, (T1) 5 mg kg^{-1} Fe (arıtma çamuru demiri) + 10 mg kg^{-1} Fe ($FeSO_4.7H_2O$), (T2) 10 mg kg^{-1} Fe (arıtma çamuru demiri) + 5 mg kg^{-1} Fe ($FeSO_4.7H_2O$), (T3) 15 mg kg^{-1} Fe (arıtma çamuru demiri) ve (T4) 15 mg kg^{-1} Fe ($FeSO_4.7H_2O$) belirlenmiştir. Araştırma sonucunda arıtma çamuru ve arıtma çamuru demir kombinasyonları kontrole oranla mısır bitkisinin yaş ağırlığı, kuru ağırlığı, bitki boyu, yaprak sayısı ve bitkinin N, K, Fe, Zn ve Cu içeriğini arttırdığı belirlenmiştir. Ayrıca bitkinin demir ihtiyacını karşılamak için arıtma çamurundaki 15 mg kg^{-1} Fe uygulamasının yeterli olacağı sonucuna varılmıştır. Bununla beraber, bu çalışmadan elde edilen sonuçlar bu deneme toprağı ve arıtma çamuru için geçerlidir ve toprak ve iklim gibi farklı koşullar altında değişebileceğinden konuda geniş kapsamlı çalışmalar yapılmalıdır.*

Anahtar kelimeler: *Mısır, demir, arıtma çamuru, verim.*

INTRODUCTION

Municipal treated sludge is the natural end products of a microbial food chain in the wastewater treatment process. Microbes feed on organic components of waste until they can no longer derive energy from it. At this point, sludge consists of mostly cellular material and stable degradation products that are considered safe for application to agricultural or forest lands. If properly managed, land application is an excellent way to dispose sludge. Waste can be applied at rates to meet crop nutrient requirements without harming the environment. Sludge contains many nutrients (N, P, and K) necessary for plant growth and development and organic matter that can improve the soil tilth (Michael *et al*., 1995; Arcak *et al*., 2000). In addition, applications of sludge can also improve soil physical properties such as aeration and water holding capacity (Pagliai and Guidi, 1980). However, sludge can contain heavy metals or other potentially toxic substances. Lead, zinc, copper, nickel, cadmium, chromium, arsenic, selenium and mercury are the heavy metals sometimes found in sludge. These substances must be reduced or confined to levels that are considered safe for both agricultural and forest crops and soils. The effect of application of sludge on P content of soil was similar to the effects of application of chemical fertilizer and control soil. In the study, P mobility and the amounts of Cu, Ni and Zn in soil and Zn content of plant increased (Garcia *et al*., 2007). Mays and Giordano (1988), determined a decline in maize yield but metal concentrations did not exceed threshold values in soil depending on sludge application. Macedo *et al.* (2012), studied the effects of sludge on yield and quality parameters of wheat and suggested that sludge can be a value nutrient source. Junio *et al.* (2011), two doses of rock phosphate (0 and 90 kg P_2O_5 ha^{-1}) and four doses of sewage sludge compost (0, 25, 50 and 75 MT ha^{-1}) were applied to soil and evaluated the concentration of heavy metals in soil and leaves of maize fertilized with rock phosphate and sewage sludge compost. The rock phosphate did not affect overall levels of heavy metals in soil, however, Cu, Zn and Pb in soil increased with application rates of sewage sludge compost. Applications of sewage sludge compost up to 75 Mg ha^{-1} did not increase the concentrations of Cu, Zn, Pb, Cd, Ni and Cr above the critical limits established by legislation. In plants, the concentrations of Cu, Zn, Pb, Cd and Cr were not affected by the application of rock phosphate, however, the Zn concentration increased and Pb concentration decreased with the application rates of sewage sludge compost. El-Dawwey *et al.* (1993), determined that the increasing sewage sludge amounts increased dry matter weight and intake of and K of wheat. They were conducted an experiment on the application of aerobically-digested sewage sludge (AES), anaerobic lagoon septic wastes (ANS), sewage sludge compost and fertilizer to soils for grass forage and feed maize production and found that the septic sludge (ANS) produced the highest forage Fe, Cu and Zn levels and was equal to compost in elevating maize stover and forage S and the forage B content. The compost produced the highest forage Ca and maize Zn (Warman and Termeer, 2005). Lombi and Gerzabek (1998), researched sewage sludge as alternative to phosphorus fertilizers and grown rape in applied sewage sludge soils. They found that the concentrations of heavy metal of rape did not exceed threshold values only Zn concentration very little increased. Giannakis *et al*. (2014), investigated the impact of municipal solid waste compost (MSW-compost) application (0, 50, and 100 t ha^{-1}) on the growth, and on nutrient and trace elements content in lettuce and tomato plants. In this study, the content of heavy metals in the tissues of plants grown in MSW-compost amended soil, remained at levels similar to those of the non-amended soil, suggesting that they do not pose a significant risk either for plant growth or public health. Moreblessing *et al*. (2016), investigated the effects of sewage sludge and its biochar on soil chemical properties, maize nutrient and heavy metal uptake, growth and biomass partitioning on a tropical clayey soil. Maize growth, biomass production and nutrient uptake were significantly improved in biochar and sewage sludge amendments (15 t ha^{-1}) compared to the control. It was also determined that biochar amendments reduced Pb, Cu and Zn uptakes by about 22% compared with sludge alone treatment in maize plants. Yanchao *et al*. (2017) evaluated the effects of sewage sludge amendment combined with green manuring on selected soil physicochemical properties of the mudflat soil in a rain-fed agro ecosystem. The results showed that SSA combined with green manuring decreased bulk density, pH, salinity, and exchangeable sodium percentage of the topsoil (0–20 cm soil layer) and increased aggregate stability, cation exchange capacity, and N and P concentration of the topsoil and the maize yield. The authors suggested that SSA combined with green manuring can be applied in coastal mudflat salt-soil amendment, which provides an innovative way to create arable land resources and safe disposal of sewage sludge. Iglesiasa *et al*. (2018), evaluated the extractability and crops (barley and maize) transfer of thirteen potentially toxic elements (PTEs) from soils that had been amended with biosolids each year for 15 years as a regular agricultural practice and found an increase in the amount of Pb, Hg, Zn and Ag in soils amended by biosolids. However, the PTE total content in croplands was still far below the thresholds established by US and European regulations and the concentration of PTEs in the barley and maize grains grown in fields repeatedly amended with biosolids was not statistically different from those grown with chemical fertilization, except for As in barley grains.

Land application of sewage sludge to calcareous soils can also be used to ameliorate iron deficiency of plants. For this reason, this study was conducted in order to determine the effect of the applications of municipal sewage sludge and Fe on yield and nutrient content of maize plant.

MATERIALS AND METHODS

A pot experiment was performed with 2 kg soil in 5 l pots with maize plant in greenhouse. The soils used were clayey loam with pH 7.9. Physicochemical properties of the experiment soil are given in Table 1. Nitrogen 200 mg kg^{-1}, phosphorus 100 mg kg^{-1} and potassium 150 mg kg^{-1} as basal fertilizers were applied to all pots. The experiment treatments were (C) control (soil), (T1) 5 mg kg^{-1} Fe (Fe in sludge) + 10 mg kg^{-1} Fe ($FeSO_4.7H_2O$), (T2) 10 mg kg^{-1} Fe (Fe in sludge) + 5 mg kg^{-1} Fe ($FeSO_4.7H_2O$), (T3) 15 mg kg^{-1} Fe (Fe in sludge), and (T4) 15 mg kg^{-1} Fe ($FeSO_4.7H_2O$). The 15 pots were arranged in a randomized complete plot design with three replications. The treated sludge was obtained from İZSU (İzmir Municipal Waste Treatment Plant in Çiğli-İzmir / Turkey). The characteristics of the treated sludge are given in Table 1.

Table 1. Some physicochemical properties of the experiment soil and sewage sludge.
Çizelge 1. Deneme toprağı ve atık çamurun bazı fizikokimyasal özellikleri.

Property Özellik	Soil Toprak	Sewage sludge Atık çamur	Property Özellik	Soil Toprak	Sewage sludge Atık çamur
pH	7.96	7.45	Available-Zn (mg kg^{-1})	0.87	-
Sand / Kum (%)	44.40	-	Available-Mn (mg kg^{-1})	15.60	-
Silt / Mil (%)	24.00	-	Available-B (mg kg^{-1})	0.48	-
Clay / Kil (%)	31.60	-	Total P (%)	-	1.36
$CaCO_3$ (%)	15.60	-	Total K (%)	-	1.25
Soluble salt / Çözünebilir tuz (%)	0.56	2.12	Total Ca (%)	-	3.95
Organic matter / Organik madde (%)	2.10	54.10	Total Mg (%)	-	0.69
Organic C / Organik C (%)	1.21	31.38	Total Na (%)	-	0.45
Total Nitrogen / Tolam Azot (%)	0.115	2.49	Total Fe (%)	-	1.14
C/N	10.52	12.62	Total Cu (mg kg^{-1})	-	156.3
Available-P / Alınabilir-P (mg kg^{-1})	2.56	-	Total Zn (mg kg^{-1})	-	104.78
Available-K / Alınabilir - K (mg kg^{-1})	116.00	-	Total Mn (mg kg^{-1})	-	396.24
Available-Ca / Alınabilir -Ca (mg kg^{-1})	4200.00	-	Total B (mg kg^{-1})	-	27.10
Available-Mg / Alınabilir - Mg (mg kg^{-1})	329.00	-	Water (105°C) (%)	-	76.30
Available-Na / Alınabilir -Na (mg kg^{-1})	232.00	-	Dry Mat. (105°C) (%)	-	23.70
Available-Fe / Alınabilir - Fe (mg kg^{-1})	3.76	-	Ash(550 °C) (%)	-	49.13
Available-Cu / Alınabilir - Cu (mg kg^{-1})	1.43	-	Fiber lost (%)	-	50.87

After applications, maize (C-955 silage maize hybrid variety) was sown (5 seed per pot, reduced to 2 plants per pot after 1 month). Each pot was irrigated daily with top water (EC=1 dS m^{-1}) during the experiment to maintain a water content of 75% water holding capacity. At harvest, the cereal plant samples were washed with top water and then with deionized water. Afterwards, the plant samples were oven-dried to constant weigh at 70 ^{0}C and then some yield parameters were determined. Element concentrations (Fe, Mn, Cu, and Zn) and P were determined using spectrophotometric analysis (Kacar, 1984). All samples of sludge and soil were air-dried, ground and then passed through a 2-mm sieve. Soil pH was measured in a water suspension (1:2 ratio). Organic matter was determined using a digestion method, total-N, available P and exchangeable K in the soils were determined using Kjeldalh-digestion, colorimetric analysis and flame-photometer, respectively (Bremner, 1965; Olsen *et al*., 1982; Knudsen *et al*., 1982). Available Fe, Cu, Zn and Mn were determined according to Linsday and Norvell (1978). Soil texture, soluble salt and lime were determined as hydrometric, conductivimetric and calcimetric methods, respectively (Bouyoucus, 1951; Richard, 1969; Allison and Moodie, 1965; Black, 1965). Total metals in sludge were determined after digestion of the soils with HCl: HNO_3 [4:1(v/v)] (Khan and Frankland, 1983). All statistical analyses were carried out with the SPPS 15.0 for Windows package. The results were analyzed by ANOVA, considering the treatments as the independent variable. The significance was tested between treatments by the LSD test as p<0.05. In addition, a multiple linear discriminant analysis was initiated to determine overall impacts of treatments to study parameters by using JMP package. The diversification between each group was expected multivariate normal. The function was determined by using the parametric method (SAS, 2014) The classification criterion is evaluated by a measure of generalized squared distance (Rao, 1973). The classification criterion was based on the pooled covariance matrix yielding a linear function; it also takes into account the prior prospects of the groups indicated treatments.

RESULTS AND DISCUSSION

The effect of applications of sewage sludge (SS) and iron on some yield parameters and content of macro and micro nutrients of maize are given in Table 2, 3, and 4, respectively. All treatments significantly affected the plant height, leaf number and above-ground biomass (fresh and dry) of maize. Similar results were obtained by some researchers (Christie *et al*., 2001; El-Naim *et al*., 2005). However, the impacts of the treatments on fresh and dry weight of roots were not significant. Sewage sludge applications in the different dose and amounts increased fresh and dry biomass but high sewage sludge applications have negative effects on these parameters (Cimrin *et al*., 2000; Qasmin *et al*., 2001). The maximum plant height (100, 67 cm) was determined in 15 mg kg^{-1} Fe application (T4) and the minimum plant height in control soil (80 cm). The similar situation was also obtained for leaf number. But, all the treatments containing Fe applied as sewage sludge or $FeSO_4.7H_2O$ increased above-ground biomass (fresh and dry) compared to the control. These results showed that the applications of sewage sludge supplied with Fe were sufficient for biomass production of maize. Sewage sludge (SS) applications increased dry biomass amount of maize and the other plant parameters (El-Dawwey, 1993; Bellamy *et al*., 1995; Lombi and Gerzabek, 1998).

The treatments had no significant effect on the contents of P, Ca, and Mg of maize but the significant effects were determined in the contents of N, K, and Na (Table 3).

Al-Nahidh (1991), stated that the application of municipal sewage sludge increased the intakes of N, P and K in maize and P content in soil. In this study, the effect of SS treatments on plant P content was not significant. Lambert and Weidensaul (1991), stated that sludge may reduce the availability of fertilizer P and sludge treatment decreased P intake from soil. Espinosa *et al.* (2000), determined the increases in the amounts of CEC and exchangeable cations, such as Ca^{++}, depending on the applications of sewage sludge.

The effects of sewage sludge applications on the content of micro-elements of maize are presented on Table 4. The treatments significantly affected the amounts of Fe, Cu, Zn and B, but no significant effects on Mn content were observed. The content of Fe, Zn, and B of maize significantly increased by treatments containing Fe (P<0.01). Similar results for Fe, Cu, Zn and Mn were obtained by some researches (Pinamonti *et al*., 1997; Cimrin *et al*., 2001). It was also reported that sewage sludge treatments increased Zn content of plant (Reed *et al*., 1991; Menelik *et al*., 1991; Lombi ve Gerzabek, 1998). Cimrin *et al*. (2000), applied sewage sludge as a P source and did not determine a change in Mn content of plant, similarly to our study.

Table 2. Effects of sewage sludge and iron applications on some yield parameters of maize.
Çizelge 2. Atık çamur ve demir uygulamalarının mısır bitkisinin bazı verim parametreleri üzerine etkileri.

Treatments Uygulamalar	Plant height Bitki boyu (cm)		Leaf Number Yaprak sayısı		Above ground fresh biomass (g/pot) Toprak üzeri yeşil biyokütle (g/saksı)		Above ground dry biomass (g/pot) Toprak üzeri kuru biyokütle (g/saksı)		Fresh root weight (g/pot) Yaş kök ağırlığı (g/saksı)	Dry Root weight (g/pot) Kuru kök ağırlığı (g/saksı)
Control	80.00±6.24	c	10.67±0.58	c	116.65±4.16	b	17.97±1.00	b	76.00±2.78	14.89±0.56
T1	87.60±10.97	bc	13.00±1.00	b	129.00±6.08	a	24.61±2.89	a	89.43±6.32	15.93±1.67
T2	92.33±15.70	abc	13.67±1.15	ab	126.47±5.51	a	23.24±2.31	a	79.38±4.93	16.26±1.61
T3	99.00±4.00	ab	14.33±0.58	ab	122.25±2.52	ab	21.00±1.00	ab	78.12±3.52	16.30±1.30
T4	100.67±2.08	a	15.00±1.00	a	125.47±1.53	a	23.57±2.08	a	80.00±4.23	16.14±1.17
CV (%)	12.03		12.89		4.59		13.54		7.61	7.82
LSD	12.946*		1.458**		7.368*		4.183*		ns	ns

*, **: P≤0,05 ve P≤0,01 düzeyinde önemli (*, **: Significant at P≤0,05 and P≤0,01).
Same letters in a column are not significantly different (Aynı harfle gösterilen ortalamalar arasında önemli fark yoktur).
ns: non-significant (önemli değil).

Table 3. Effects of sewage sludge and iron applications on the macro elements content of maize.
Çizelge 3. Atık çamur ve demir uygulamalarının mısır bitkisinin makro element içeriği üzerine etkisi.

Treatments	N	P	K	Ca	Mg	Na
Uygulamalar	$g\ kg^{-1}$					
C	27.23±0.31 b	1.77±0.06	27.67±1.24 b	6.63±0.40	2.63±0.15	0.16±0.06 b
T1	30.43±1.10 a	1.83±0.15	36.43±1.82 a	7.17±0.76	3.07±0.15	0.20±0.02 ab
T2	31.13±1.70 a	1.90±0.20	35.03±2.26 a	7.93±0.60	3.13±0.38	0.23±0.05 ab
T3	30.40±0.26 a	1.80±0.10	35.97±1.54 a	7.47±0.84	3.23±0.40	0.25±0.06 a
T4	30.33±0.29 a	1.63±0.06	36.50±3.12 a	7.33±1.46	3.27±0.29	0.16±0.01 b
CV (%)	5.42	7.88	11.39	11.88	11.21	24.23
LSD	2.641**	ns	4.721**	ns	ns	0.703**

*, **: P≤0,05 ve P≤0,01 düzeyinde önemli (*, **: Significant at P≤0,05 and P≤0,01).
Same letters in a column are not significantly different (Aynı harfle gösterilen ortalamalar arasında önemli fark yoktur).
ns: non-significant (önemli değil).

Table 4. Effects of sewage sludge and iron applications on the micro elements content of maize.
Çizelge 4. Atık çamur ve demir uygulamalarının mısır bitkisinin mikro element içeriği üzerine etkisi.

Treatments	Fe	Cu	Zn	Mn	B
Uygulamalar	$mg\ kg^{-1}$				
C	129± 2.07 d	6.93±0.06 b	20.24±0.92 b	37.66±2.72	7.19±0.06 c
T1	155±10.60 c	7.63±0.42 a	23.82±2.03 a	38.51±3.29	9.86±1.52 b
T2	175±11.83 bc	7.48±0.45 a	24.20±2.77 a	39.12±4.47	11.68±0.74 a
T3	185±16.00 ab	7.40±0.36 a	25.17±0.22 a	40.69±0.35	12.14±0.69 a
T4	205±12.96 a	7.30±0.30 ab	24.92±1.26 a	40.28±2.04	7.37±0.07 c
CV	16.85	5.20	9.86	6.93	23.44
LSD	23.661**	0.423*	3.256**	ns	1.805**

*, **: P≤0,05 ve P≤0,01 düzeyinde önemli (*, **: Significant at P≤0,05 and P≤0,01).
Same letters in a column are not significantly different (Aynı harfle gösterilen ortalamalar arasında önemli fark yoktur).
ns: non-significant (önemli değil).

A multi linear discriminant analysis had been used to determine overall impacts of sewage sludge and Fe applications on parameters used in the present study (Figure 1). This analysis considers all plant and soil properties used in this study. Each group was arranged for each treatment and effects were set to be distance between each group. Significance of difference between treatments is established by distance between two circles on the Figure 1 with α=0.05. Differentiations in position of groups in the figures of discriminant analysis also showed that all treatments appear to be significantly influenced on study parameters; whereas, these differences were explained by 86% (R^2=0.86). Plots under T1 and T4 treatments were observed to have higher significant impacts in comparison to T2 and T3 treatments under considerations of all parameters together. Observations for plots under T1 treatment showed that N content, plant dry, and fresh weights were most affective properties.

Comparable results were also monitored for T2 treatment. However, plant height for T3 treated plots and N of leaves and plant height for T4 treated plots showed difference in comparison to T1 and T2. Phosphorus contents were negatively influenced by all (T1, T2, T3, and T4) treatments in comparison to those under control.

In conclusion, the applications of T1, T2 and T3 increased the yield and the amounts of N, K, Cu and Zn of maize as much as T4 ($FeSO_{4}.7H_2O$) application. But, the effect of these treatments on the amounts of P, Ca, Mg and Mn of maize was not significant. The most effective treatments on Fe content of maize were T3 and T4 applications. According to these results, application of 15 mg kg^{-1} Fe in sludge (T3) is sufficient for Fe need of maize. However, further researches are needed on this field. Since the chemical properties of sewage sludge from every treated plant may vary, the characteristics of sewage sludge must be well defined before application to the soils. The obtained results from this study were valid only for this preliminary study for soil and sewage sludge and should be used without generalization as they can vary under different conditions such as soil and climate.

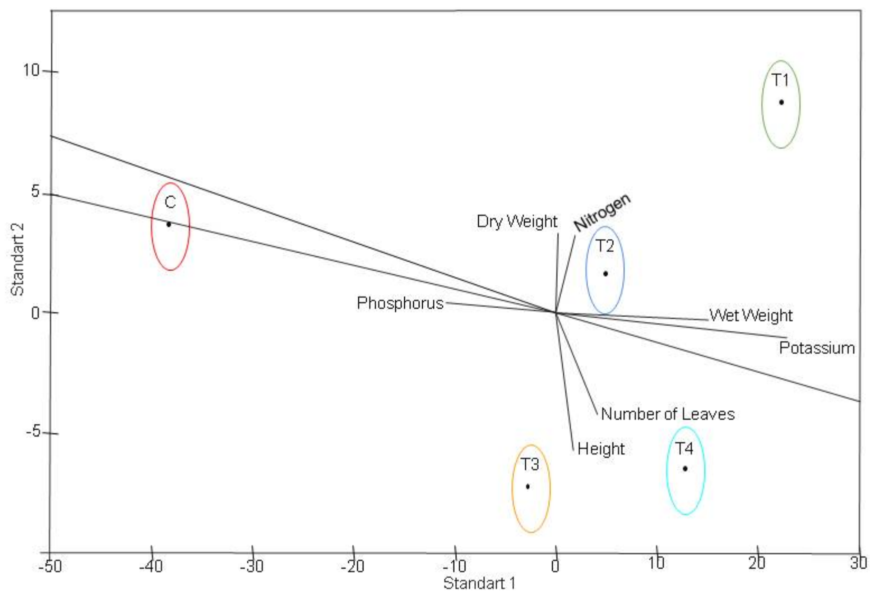

Figure 1. The overall impacts of sewage sludge and Fe applications on parameters used in the present study (C: Control; T1: Treatment 1; T2: Treatment 2; T3: Treatment 3; T4 Treatment 4).
Şekil 1. Atık çamur ve demir uygulamalarının mısır bitkisinin bu çalışmadaki tüm parametreler üzerine etkileri (C: Kontrol; T1: Uygulama 1; T2: Uygulama 2; T3: Uygulama 3; T4 Uygulama 4).

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