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Ecophysiological responses of *Zea mays* L. against thermal power plant fly ash applications

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Abstract

Thermal power plant fly ash is one of the most important concerns of this form of energy generation, as it is the most important waste generated by burning coal in a thermal power plant. This kind of fly ash contains elements like Fe, Al, Si, Ca, Na, and K which can be beneficial or harmful to plants depending on the concentration. To evaluate the effect of thermal power plant fly ash on the ecological system, it is necessary to analyze the ecophysiological responses of plants. *Zea mays* L. (corn) is a worldwide consumed plant species that has been cultivated for 10000 years and it is an important model organism for genetics and biology. In this study, it was aimed that to observe ecophysiological responses of corn against thermal power plant fly ash applications. For the experimental period, control (0 ppm), 500, 1000, 2500, 5000, and 7500 ppm of fly ash applications were set. The experiments took 14 days, and at the end of the experimental period % germination, hypocotyl and radicle lengths, seedling vigor index were calculated. It was observed that 500 to 5000 ppm fly ash applications were stimulated the seed germination, stem and root development, and also seedling vigor index (SVI), but 7500 ppm fly ash applications were inhibited by all ecophysiological parameters. We can say that lower than 5000 ppm fly ash can be useful for agricultural practices, however above 5000 ppm level it is harmful to plant development.

Keywords: ecophysiology, fly ash, *Zea mays*

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Zea mays L.'nin termik santral uçucu kül uygulamalarına karşı ekofizyolojik tepkileri

Özet

Termik santral uçucu külü, bir termik santralde kömür yakılarak üretilen en önemli atık olduğu için bu tür enerji üretiminin en önemli endişelerinden biridir. Bu tür uçucu kül, konsantrasyona bağlı olarak bitkiler için yararlı veya zararlı olabilen Fe, Al, Si, Ca, Na ve K gibi elementler içerir. Termik santral uçucu külünün ekolojik sistem üzerindeki etkisini değerlendirmek için bitkilerin ekofizyolojik tepkilerini analiz etmek gerekir. *Zea mays* L. (mısır), 10000 yıldır yetiştirilen, dünya çapında tüketilen bir bitki türüdür ve genetik ve biyoloji için önemli bir model organizmadır. Bu çalışmada, termik santral uçucu kül uygulamalarına karşı mısırın ekofizyolojik tepkilerinin gözlemlenmesi amaçlanmıştır. Deney periyodu için kontrol (0 ppm), 500, 1000, 2500, 5000 ve 7500 ppm uçucu kül uygulamaları yapılmıştır. Denemeler 14 gün sürmüş ve deneme süresi sonunda % çimlenme, hipokotil ve kök uzunlukları, fide canlılık indeksi hesaplanmıştır. 500 ila 5000 ppm uçucu kül uygulamalarının tohum çimlenmesini, gövde ve kök gelişimini ve ayrıca SVI'yı uyardığı, ancak 7500 ppm uçucu kül uygulamalarının tüm ekofizyolojik parametreler tarafından engellendiği görülmüştür. 5000 ppm'den daha düşük uçucu külün tarımsal uygulamalar için faydalı olabileceğini, ancak 5000 ppm seviyesinin üzerinde bitki gelişimine zararlı olduğunu söyleyebiliriz.

Anahtar kelimeler: ekofizyoloji, uçucu kül, *Zea mays*

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1. Introduction

Coal currently accounts for 30% of the world's primary energy and its share in electricity generation is expected to increase to 34% by 2040. Due to the large reserves of lignite coal (18.9 Mt) in Turkey, the share of this fuel in electricity generation was high at 37% in 2018 [11]. It is a fact that the increase in electricity demand in the world and Turkey, and accordingly, an increase in the number of thermal power plants is expected today and in the future. The disposal of Fly Ash, which is formed by the activities of these power plants, creates a great concern globally. In addition, this problem becomes serious for developing countries [12, 22, 23, 24]. Afşin-Elbistan, Çatalagzi, Çayırhan, Kangal, Kemerköy, Orhaneli, Seyitomer, Soma, Tunçbilek, Yatağan and Yeniköy are some of them operating in Turkey. A significant amount of fly ash is produced in these facilities operating in Turkey [25]. Fly Ash (FA) production is highly dependent on coal quality, with very high ash content accounting for 10-30% of FA formation [14, 15, 16].

Fly ash is a waste product produced by holding the particles in flue gases in electro filters during the combustion of coal-fired thermal power plants in the boilers [1]. Micro and macronutrients found in coal are usually concentrated in the ash [10]. The mineralogical, physical, and chemical properties of fly ash depend on the nature of the main coal, combustion conditions, type of emission control devices, and storage and processing methods [17]. Fly ash consists of fine particles that contain leachable heavy metals and is therefore classified as a toxic waste [2]. Considering the dust pollution caused by its storage and fineness, its costly, cycle poses a serious problem [13]. However, it is rich in some elements and composites (such as metals and salts) and therefore has some potential to be used as raw material [2]. Their use with soil likely improves soil physicochemical properties such as pH, texture and water holding capacity (WHC). Alkaline FA supplementation with a pH above 9.07 can reduce soil acidity to a suitable level for agriculture and increase the availability of trace metals, SO_2 and other nutrients [12]. The coal fly ash mainly contains Si, Al, and Fe as a major element concentration along with a substantial amount of Ca, Na, K and Ti [3]. The high concentration of nutrients in fly ash improves the edaphic properties of the ecological environment, which increases plant growth [4]. Each potential application for fly ash results in three main advantages: first, the use of a zero-cost raw material, secondly, the conservation of natural resources, and thirdly, the elimination of waste [2].

Zea mays L. subsp. *mays*, often called corn or maize, belongs to the Andropogoneae grass tribe of the Gramineae (Poaceae) family. Grasses appeared 55-70 million years ago (mya) and later diversified to include all major grain crop species in addition to about 10,000 untamed relatives. The origin of maize as a model organism can be traced back to early work by Gregor Mendel in 1869 using maize to support his earlier breeding experiments in *Pisum* (pea) [19, 20, 21]. It ranks below corn, wheat and sorghum, but well above rice in terms of nutritional value. Corn grain contains starch as major components and other components such as protein, fat, fiber, sugar and ash. Due to the high prices of green cobs and the green straw used as fodder, farmers benefit from corn planting. However, during cultivation, the maize crop requires special attention in terms of soil nutrient management [18].

This study, it was aimed to observe the ecophysiological responses of maize (*Zea mays*) to thermal power plant fly ash applications, since it is a model plant due to its easy cultivation, high growth, and biomass production [9]. This study was carried out to determine the possible effects of thermal power plant ash on Zea Mays, which has an important place in agricultural production, as the regions and areas of influence of thermal power plants can be close to agricultural production areas.

1. Materials and methods

For the experimental period, control (0 ppm), 500, 1000, 2500, 5000 and 7500 ppm of fly ash applications were set. Pots with 1 kg capacity used as seedbeds (Figure 1 a, b). Different fly ash concentrations were weighed and mixed with 500 g soil. Then fly ash added to soils set in the pots. Corn (cv. Sweetcorn) seeds were soaked in soil-filled pots and watered with 100 ml distilled water. Experiments were conducted in a growth chamber (Sanyo, MLR 350) for 14 days at 22°C, with a photoperiod of 16 hours light/8 hours dark. At the end of the experiment period, % germination [5], hypocotyl and root lengths, seedling vigor index [6] were measured by caliper and indicated in cm and calculated. In the study, Eskişehir Technical University Faculty of Science Plant Ecology Laboratory was used.

The germination percentage of seeds was calculated as follows [27]:

$$\text{Germination rate}=(G/S)*100$$

(G: Number of seeds germinated, Q: Total number of seeds used)

SVI value is calculated as follow [6]:

$$SVI=A+(B*C)$$

(A= Root length, B=Stem length, C=Germination rate)

Figure 1a, b: A set of pots used for experimental study.

2.1 Data Analysis

The data obtained from experiments were tested statistically with the spss statistics 21 package program, ANOVA tests, with a sensitivity of $p<0.05$. Germination rate, SVI, Hypocotyle length and Radicle length data were statistically (Tukey) analyzed. The data show a normal distribution. Data that did not show normal distribution were converted to "ln" (log) form and normal distribution was achieved. Data that could not be analyzed are marked with "λ" in Table 1.

2. Results

When the results of the study were examined, it was seen that the thermal power plant ash application from 1000 ppm to 5000 ppm had a positive effect on the stem growth of *Zea mays*, while it had a negative effect at 7500 ppm (df=5.4, $p<0.05$). In applications above 5000 ppm, a sudden decrease in ecophysiological parameters was observed.

While the lowest stem growth was seen in the control group (1.1 cm), the lowest root (1.38 cm) development was seen in 500 ppm application (Table 1). For each group, values followed by the same letter in each column do not differ according to the Tukey test ($P<0.05$).

Table 1. Data of seedlings exposed to fly ash

	Hypocotyle (cm)	Radicle (cm)	% Germination	SVI
Control	1.10 a	1.73 a	60.00 λ	67.73 a
500 ppm	5.45 a	1.38 a	80.00 λ	437.38 b
1000 ppm	11.30 b	3.35 a	40.00 λ	455.35 b
2500 ppm	14.86 b	3.40 a	100.00 λ	1489.40 c
5000 ppm	15.12 b	3.96 a	100.00 λ	1515.96 c
7500 ppm	4.70 a	2.48 a	100.00 λ	472.48 b

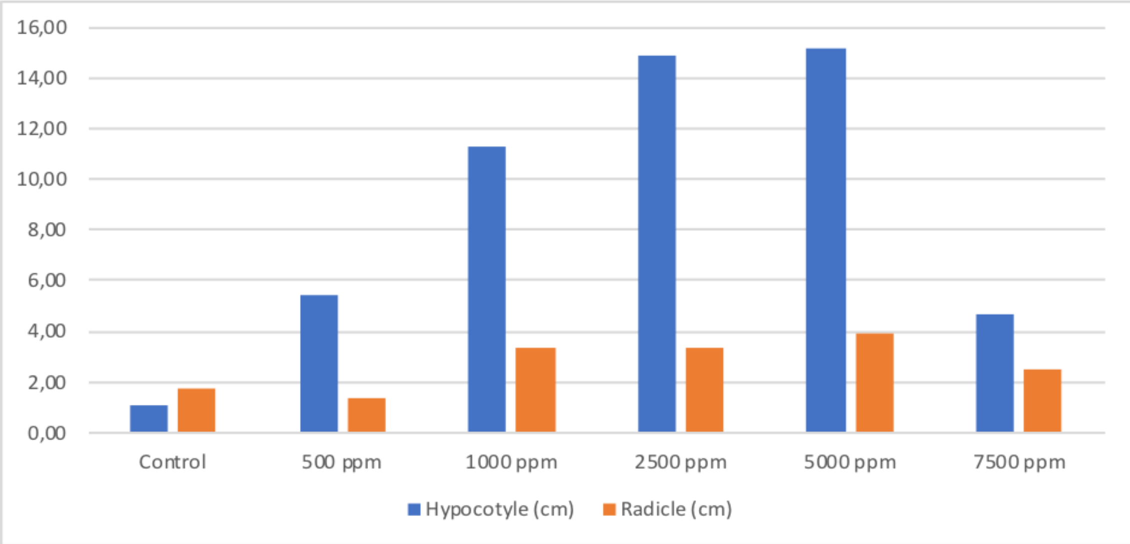

Figure 2. Mean hypocotyl and radicle lengths of seedlings (cm)

When the seedling vigor index data are compared, parallelism is observed with the stem developments. Because there is a correlation between stem development and SVI (Figure 3). As a result of the study, the highest experimental results were observed [radicle length (3.96 cm), hypocotyl length (15.12 cm) and SVI (1515.96)] in 5000 ppm fly ash application.

When groups are compared in terms of germination percentage, there is no significant change (no statistical data). Thus, we can say that thermal power plant ash applications do not affect germination. Ash applications do not seem to have a significant effect on root development (Table 1).

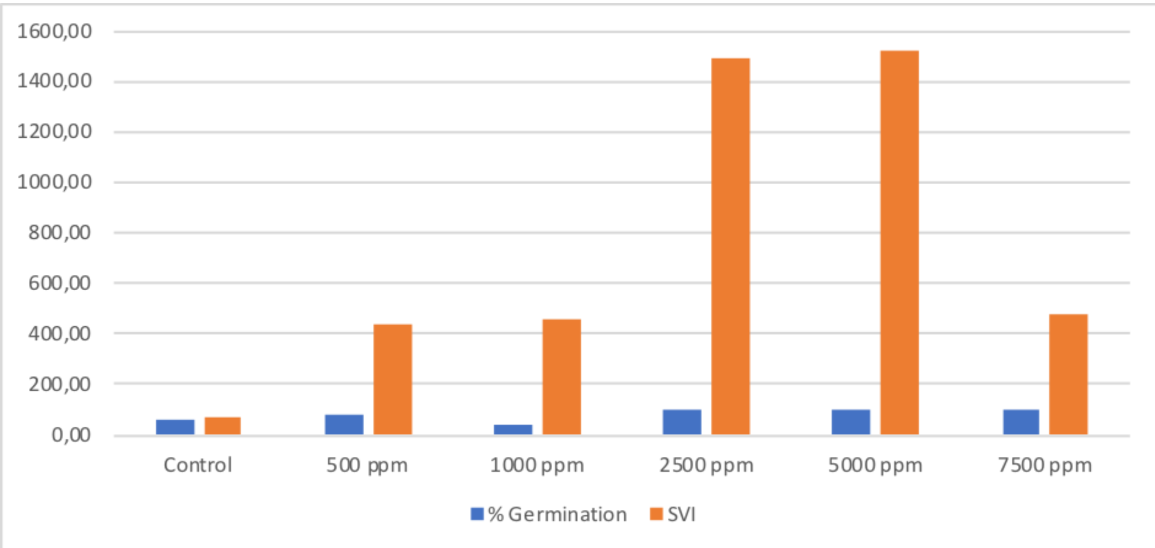

Figure 3. % Germination and seedling vigour index (SVI) of seedlings (cm)

3. Conclusions and discussion

Jala & Goyal (2006) mentioned some beneficial effects of applying fly ash to soil systems: it reduces the consumption of soil improvement agents (such as fertilizer or lime) and can reduce the mobility and availability of metal in the soil. Similarly, to Jala & Goyal's (2006) findings, according to our study, it was determined that lower than 5000 ppm fly ash can be useful for agricultural practices in *Zea mays* [7].

On the other hand, harmful effects such as a decrease in the bioavailability of some nutrients from the application of alkaline fly ash have also been reported [4].

Correlatively to Blissett & Rowson (2012) we found out that above 5000 ppm level of fly ash applications were harmful to plant development in *Zea mays* [4].

Kosnar et al. (2018) showed that polycyclic aromatic hydrocarbons (PAH)-contaminated fly ash application to the soil had no adverse effects on maize growth as well as on the biomass yield. They have applied the only 1% concentration of fly ash for *Zea mays*. However, we found out that 7500 ppm fly ash application was inhibiting ecophysiological parameters such as plant development, germination percentage and seedling vigour index [8].

We can say that lower than 5000 ppm fly ash can be useful for agricultural practices, however above 5000 ppm level it is harmful to plant development.

Although we mentioned the inhibitory effect of 7500 ppm fly ash in our study, Geetanjali et al. (2017) suggested that the use of fly ash and various fertilizers together, the inhibitory dose may change in mixtures created with fly ash and various fertilizers [13].

Dash et al. (2015) stated in their study that although fly ash applications can be used to increase productivity in agricultural activities, the effects of heavy metal accumulation that may occur in soil and plants on the environment and human health should be investigated. In this study we have done, we can say that, similar to Dash et al. (2015), the application of fly ash over 5000 ppm has negative effects on plant and human health [10].

Usmani et al. (2019) determined that fly ash increased the germination percentage of the plants they used in their study (*L. esculentum* and *S. melongena*), but in our study, it was determined that the application of fly ash did not affect the germination percentage of *Zea mays* [12].

Singh et al. (2008) stated in their study that fly ash application caused significant reductions in growth, biomass, and yield responses of *Beta vulgaris*. For this reason, the thing to be considered while applying fly ash to increase productivity in agriculture should be the reaction of the plant species to be selected, because, in some species (for example, while the application of fly ash shows a positive effect in *Zea mays*, a negative effect is observed in *Beta vulgaris*), negative effects can be seen as well as positive effects [16].

Panigrahi et al. (2014) observed that the productivity of *Oryza sativa* was improved as the amount of fly ash in the soil where it was grown increased. Contrary to Panigrahi et al.'s findings, we found out that arising amount of fly ash in medium causes inhibition of productivity in *Zea mays* [26].

Muduli et al. (2014) established pot experiments by using *Vigna radiata* and *Vigna mungo* as trial material and adding fly ash at different rates to the soil. As a result of their observations, they reported that seed germination was seen in fly ash-treated plants like control [17]. No nutrient deficiency or phytotoxicity was observed in the same experiment. Similarly, to Muduli et al.'s findings, we observed that increasing fly ash application did not cause any change in germination percentage.

Singh and Sukul (2019) conducted a study on *Zea mays* and reported that 20% fly ash treatment was the best performer in obtaining economic efficiency when the harvest index was considered [18]. Contrary to the findings of Singh and Sukul, we observed that 7500 ppm fly ash application decreased ecophysiological parameters in maize.

As observed in the literature, fly ash can be used as a yield enhancer in agricultural areas, but the degree of usefulness of fly ash differs between plant species. For this reason, fly ash can be used in fertilizer-like applications in agriculture at a specific level for the plant species to be cultivated.

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