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Article

Dense Cover, But Not Allelopathic Potential, of Naturalised Alien *Cenchrus echinatus* L. Threatens the Native Species in the Urban Vegetation

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Abstract: Exotic plants are usually problematic for the native species where they coexist. This study evaluated the effect of naturalised alien *Cenchrus echinatus* L. on native plants in the urban vegetation. A field trial was conducted to assess the effect of this species on cover and diversity of the native vegetation. The allelopathic potential of such species was examined. Plots comprising *C. echinatus* had lower cover of some native species. Lower floristic diversity was observed at more dense cover of this plant. The soil under *Cenchrus* attained lower N, P and K contents. This soil had no effect on germination and growth of the native species. It also comprised germinable seeds of some species which were absent from the standing vegetation. Exotic *C. echinatus* may exert a negative effect on the native vegetation of the urban plant communities. Dense cover of *Cenchrus* may inhibit germination of native species, leading to reduction in their cover. The reduction in cover and diversity of native species was not attributed to allelopathy. These results suggest that naturalised *C. echinatus* may be more competitor than the native ones, particularly at higher densities. Furthermore, it may represent a threat for the native plants in the urban vegetation.

Keywords: naturalised alien species; allelopathy; *Cenchrus echinatus*; weeds; floristic diversity; urban ecology

1. Introduction

In many parts of the world, invasion by alien plants usually represents a threat to the natural ecosystems. The alien species caused significant reduction in the resident species' diversity, disturbance in community structure, inhibition in vegetation growth and pronounced modification in soil bioprocesses [1–5]. These alien species have been introduced from a certain region to another by human activities either accidentally or intentionally [6]. Due to their destructive effects, scientists had to do highlights on these species and understand how biological invasions proceed and affect biodiversity. Consequently, it would be necessary to search for solutions to save the natural ecosystem [7]. Numerous studies have been conducted to show the effects of alien species. Moreover, they were increasing recently. However, most of these studies addressed the effect of invasive species, and little is known about the effects of naturalised ones. Therefore, it was necessary to fill this gap in knowledge.

Invasion success may be attributed to many factors that facilitate the dominance and wide spread of these species. Allelopathy and competition are key factors contributing towards successful establishment of alien species in the invaded communities [8]. Exotics may have stronger competitive ability for resources than native ones, causing adverse impacts or excluding the natives from their community [9,10]. This high competitive ability may be attributed to some of performance-related

traits, such as high growth rate, leaf-area allocation, size and fitness, which promote invasion under different environmental conditions [11,12]. Dense cover of a species certainly facilitates competition of exotics. On the other hand, these species may produce allelopathic compounds that can manifest substantial inhibition for the associated plants directly throughout suppressing germination and growth performance, or indirectly by affecting soil microbes [8]. These compounds may be released into the soil via different methods such as exudation from plant roots, leaching from leaves, or decomposition of plant litter [13,14]. Both mechanisms seem to play, at least, a partial role in the substantial decrease in the abundance of resident species in the invaded communities. Since naturalised species are a subcategory under the alien ones and extend through wide areas [15], they may exhibit adverse effects as the same as the alien species do. In this investigation, we will study the effect of apparent cover and allelopathic potential of *Cenchrus echinatus* L., a naturalised alien species in Egypt, on the native associates. We also will examine its allelopathic potential using its rhizosphere soil that may contain allelopathic compounds.

Globally, the urban expansion continues to grow with significant increment in population growth and human activities. Urban green areas are considered as crucial ingredients of newly urbanized communities that necessarily attract citizens. Urban ecology is also considered as a field of interest for ecologists to study. Due to urbanization and plantation practices, new soils can be derived from old agricultural fields and small drainage canals and introduced into this region to be more suitable for plantations of gardens and parks. This practice may permit dispersal of plant species to this habitat. Consequently, urban green spaces may become hot points for non-native species, and it would be necessary to be in focus [16].

Non-native species are more closely associated with urban environment than resident ones [17]. This association may be due to influx of their propagules [18], habitat heterogeneity [19] and their ability to adapt with high levels of disturbances [20]. For these reasons, the urban environment accommodates high number of exotics that dominate a wide range of habitats and displace the natives [21]. Consequently, the presence of non-native plants in urban vegetation, in particular, may threaten the native species. Several studies emphasized the harmful effects of alien species on the associated species [22,23]. However, studies testing the effect of naturalised aliens in new urban areas are somewhat little.

Cenchrus echinatus L. is an annual weed species, native to tropical America and it has been introduced as a garden weed in Egypt [6]. It has also been recorded in gardens and parks of newly urbanized cities [24–26]. This plant could reproduce by seeds which are spread widely within their spiny fruits. Fruits with burrs can easily attach to animals, vehicles and clothing. They may also be dispersed by water and in contaminated agricultural products. It has the high capacity to spread and establish in newly reclaimed areas [27]. This species was recorded as naturalised alien species in Egypt [6,28]. The allelopathic effect of this species was scarcely explored. In this regard, previous studies investigated that the methanol and aqueous extracts from *C. echinatus* shoot and root extracts can to some extent inhibit the seed germination and growth criteria of some weed and crops [29–31]. Nevertheless, this is insufficient baseline work in the field of ecological allelopathy. In addition, its potential negative effects, as an alien species, in different plant communities are still unknown. Therefore, it was necessary to gather enough information about this. Our field observations indicated the presence of such species in the urban gardens and parks, with a clear reduction in cover of the native vegetation. The main hypothesis of this study was that the dense cover of *C. echinatus* in field may inhibit germination or, at least, reduce cover of the native species. This hypothesis could be tested in different ways. First, the covering areas and diversity of the native species were measured, in a field-based study, in selected sites comprising such species as well as locations completely free from it. Second, testing the seed bank in the soil in different sites dominated by *C. echinatus*. Existing of germinable/viable seeds in the location dominated by the alien species and free from the species observed in the seed bank may provide a proof for competition and/or allelopathy. As density of *Cenchrus* increases, the potential measured floristic diversity decreases. This can be assessed by measuring the diversity indices at different densities of *Cenchrus*. In addition, measurement of nutrient availability in soils of these sites may provide if this species is a strong competitor or not due

to its potential nutrient withdraw. Third, the allelopathic potential of this species can be tested using the soil collected from sites with and without *Cenchrus*, as the rhizosphere soil of this species may contain allelopathic candidates inhibiting germination and growth of some target native species.

2. Results

2.1. Floristic Composition

In the vegetation involving *Cenchrus echinatus*, ten weed species belonging to five families were detected. The half of these species falls within the members of Poaceae, while the remaining species were belonging to other five different families of equal contribution. Besides, seven of these species were annuals (Table 1).

Table 1. Mean coverage values (m²) (mean ± SE) of the plant species detected in the *Cenchrus*-free and *Cenchrus*-infested plots.

Species	Family	<i>Cenchrus</i> -Free Plots	<i>Cenchrus</i> -Infested Plots
<i>Amaranthus viridis</i> L. †	Amaranthaceae	39.82 ± 4.23	15.10** ± 4.41
<i>Apium leptophyllum</i> Pers. †	Apiaceae	15.60 ± 3.48	3.9** ± 0.45
<i>Cynodon dactylon</i> Pers. ††	Poaceae	142.21 ± 13.25	97.38** ± 9.46
<i>Dactyloctenium aegyptium</i> (L.) Willd. †	Poaceae	3.30 ± 0.64	0.0** ± 0.0
<i>Dichanthium annulatum</i> (Forssk.) Stapf ††	Poaceae	19.28 ± 4.48	8.50 ± 3.86
<i>Digitaria sanguinalis</i> (L.) Scop. †	Poaceae	16.38 ± 3.18	11.90 ± 3.27
<i>Eragrostis pilosa</i> (L.) P.Beauv. †	Poaceae	49.74 ± 8.42	14.81** ± 3.50
<i>Oxalis corniculata</i> L. ††	Oxalidaceae	17.11 ± 6.79	9.44 ± 2.33
<i>Euphorbia peplus</i> L. †	Euphorbiaceae	4.35 ± 0.60	0.35** ± 0.26
<i>Plantago lagopus</i> L. †	Plantaginaceae	17.00 ± 2.54	3.63** ± 2.63

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* P < 0.01 † Annual †† Perennial.

2.2. Effect of *Cenchrus echinatus* L. on Vegetation

In general, cover of most of the native species was reduced in the *Cenchrus*-affected plots (Table 1). All annuals were significantly affected (P<0.01). Amongst them, *Dactyloctenium aegyptium* seemed to be displaced completely from the plots with *Cenchrus*. Besides, *Euphorbia peplus* was markedly affected in comparison with the remaining annuals. For perennials, it was clear that cover of the cultivated *Cynodon dactylon* was significantly declined (P<0.01) in the plots comprising *Cenchrus*, whilst the remaining perennials were not affected (Table 1).

With respect to the measured diversity indices, there was a remarkable reduction trend for them as the density of *Cenchrus* increases (Figure 1). The negative effect of this species on plant diversity varied with respect to the measured index and the cover value of *Cenchrus*. In more detail, the species richness was not affected by the coexistence of *Cenchrus*. However, the degree of inhibition in the remaining diversity indices (Shannon-Wiener, Evenness and Simpson indices) depended on the cover of the alien species (Figure 1). Simpson index was significantly reduced at the cover of *Cenchrus* $\geq 70\%$, while both evenness and Shannon-Wiener indices were reduced at *Cenchrus* cover $\geq 80\%$ (Figure 1). Besides, all of these indices were inversely correlated with the cover of the alien *C. echinatus* (Table 2).

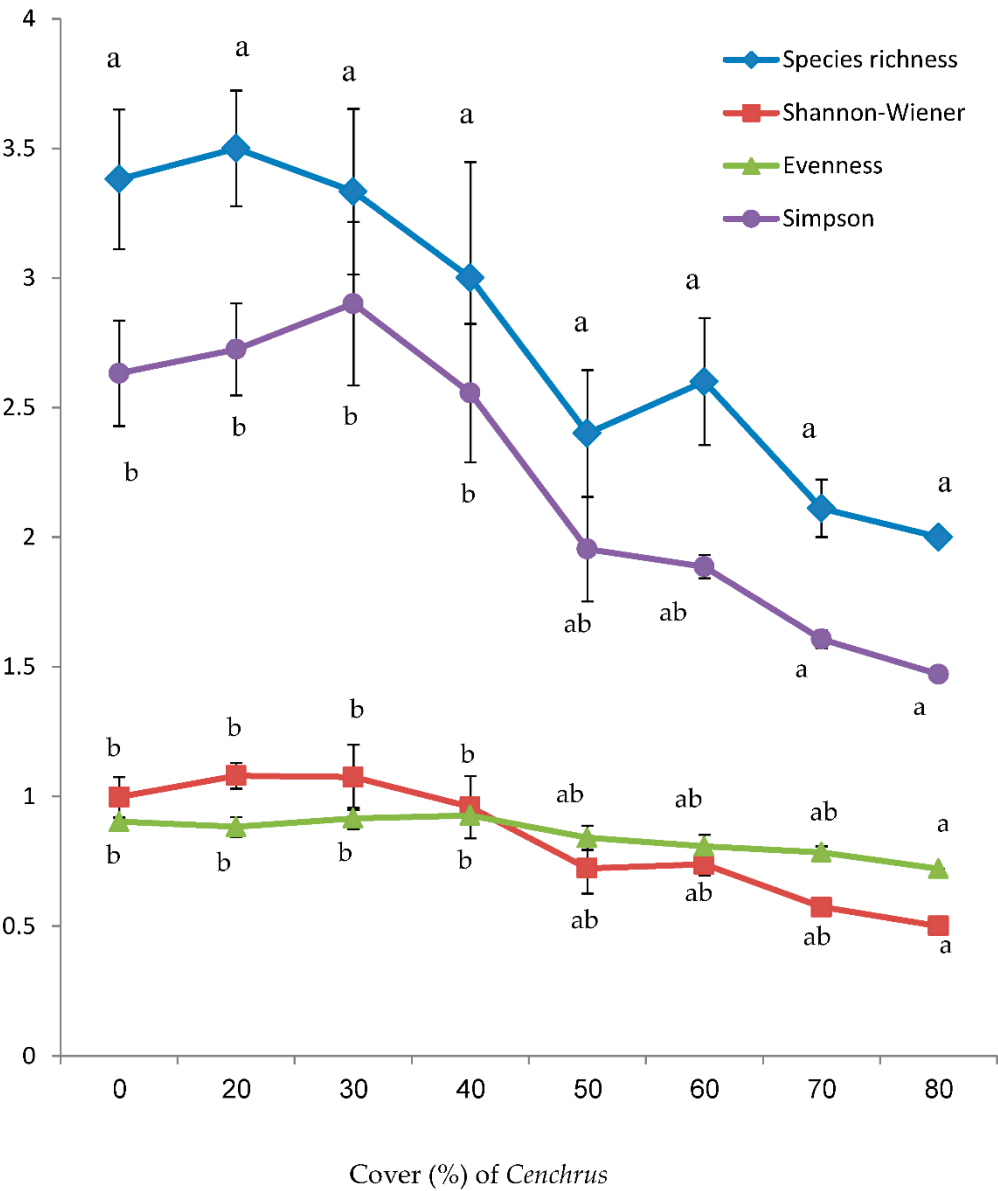


Figure 1. Measured diversity indices (Mean \pm SE) in relation to the different densities (%) of *C. echinatus*. Density at 0 value represents *Cenchrus*-free stands. Values sharing the same letter are statistically similar (at $P < 0.05$) within the same parameter.

Table 2. Correlation coefficients (r) between the measured diversity indices and the cover of *C. echinatus* L.

Diversity indices	Cover of <i>Cenchrus</i>
Species richness	- 0.54**
Shannon index	- 0.70**

Evenness	- 0.35*
Simpson index	- 0.71**

* P < 0.05, ** P < 0.01.

Regarding the investigation of the soil seed bank in the plots with *Cenchrus*, four species were found to be emerging (Table 3). These species were absent in the *Cenchrus*-free plots. The highest numbers of seeds were recorded for *Dactyloctenium aegyptium*, after which the number of germinating seed of both *Amaranthus viridis* and *Euphorbia papulus* were statistically similar. Fewer numbers of seeds were detected for *C. echinatus* itself (Table 3).

Table 3. Number of germinating seeds of the species per pot detected in the seed bank in the soil dominated by *C. echinatus* compared with the *Cenchrus*-free sites.

Species	Life Span	<i>Cenchrus</i> -Free Sites	<i>Cenchrus</i> -Infested Sites
<i>Amaranthus viridis</i> L.	Annual	-	9.72** ± 1.01 b
<i>Cenchrus echinatus</i> L.	Annual	-	2.73** ± 0.33 a
<i>Dactyloctenium aegyptium</i> (L.) Willd.	Annual	-	14.80** ± 0.90 c
<i>Euphorbia peplus</i> L.	Annual	-	9.64** ± 0.98 b

- Not detected. ** P < 0.01.

2.3. Effect of *C. echinatus* on Soil Properties

In terms of soil criteria, the plots with *Cenchrus* attained significantly lower contents of available macronutrient; namely nitrogen, phosphorus and potassium. However, these plots had higher amounts of available zinc (Table 4). The remaining soil properties were statistically similar in all plots.

Table 4. Soil physicochemical properties (mean ± SE) in the *Cenchrus*-free and *Cenchrus*-infested plots.

Soil Properties	<i>Cenchrus</i> -Free Sites	<i>Cenchrus</i> -Infested Sites
Sand (%)	48.39 ± 2.15	49.00 ± 1.60
Silt (%)	32.62 ± 1.58	32.02 ± 1.50
Clay (%)	18.99 ± 0.93	18.78 ± 0.70
pH	7.98 ± 0.03	7.92 ± 0.03
EC (μS cm ⁻¹)	377.54 ± 15.50	377.08 ± 10.50
CaCO ₃ (%)	2.47 ± 0.09	2.56 ± 0.07
OC (%)	1.97 ± 0.07	2.05 ± 0.05
Available nutrients (mg kg ⁻¹ soil)		
N	67.2 ± 1.50	51.12** ± 3.90
P	12.55 ± 0.42	10.50** ± 0.45
K	411.02 ± 5.70	361.15** ± 6.20
Zn	1.60 ± 0.13	6.10** ± 0.31
Cu	2.28 ± 0.13	2.45 ± 0.14

** P < 0.01.

2.4. Allelopathic Potential of *C. echinatus*

The results indicated that the soil under *Cenchrus* had no effect on germination and growth of three target native species (Figure 2).

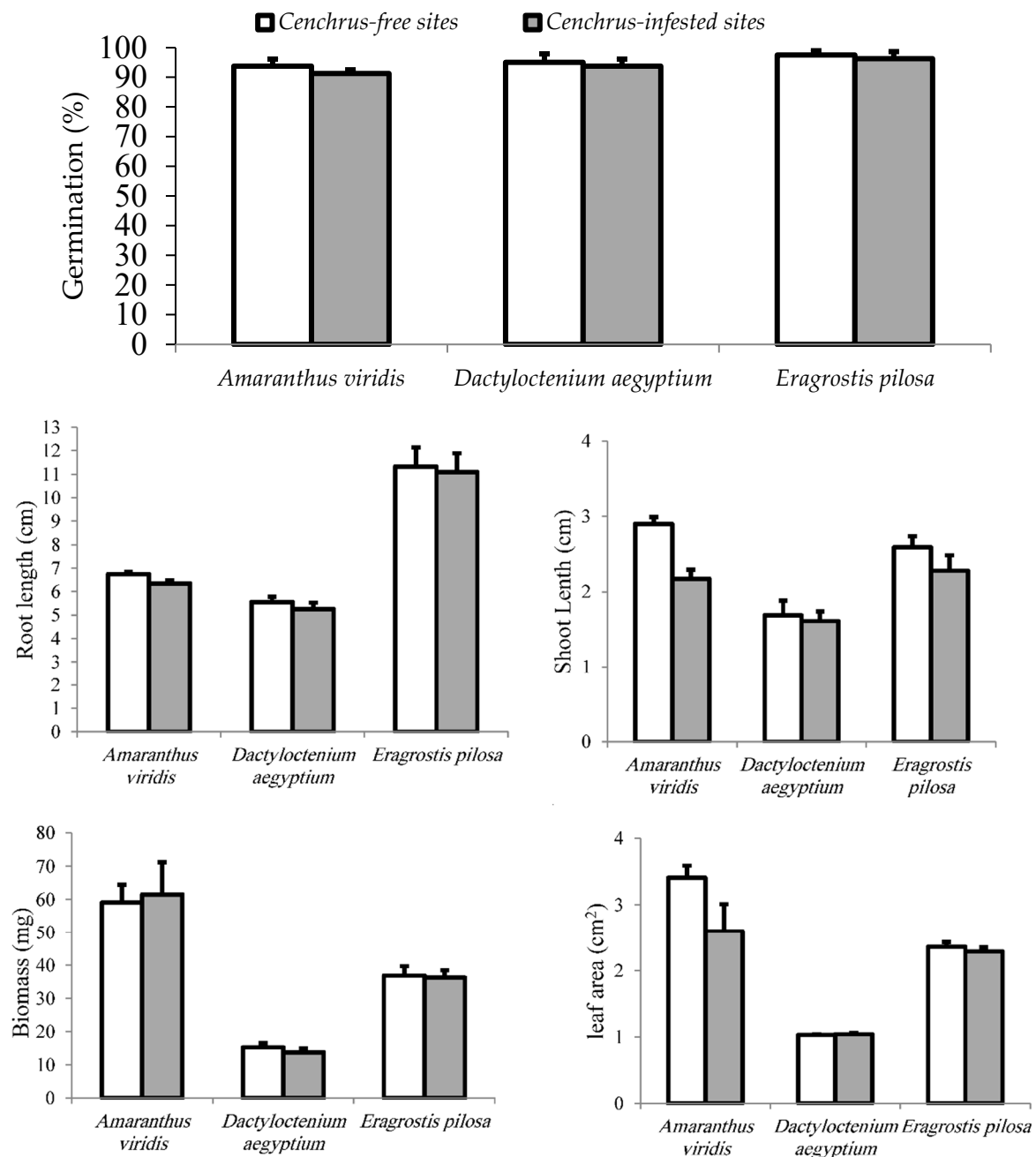


Figure 2. Germination (%) and the measured growth criteria (Mean, bars represent standard errors) of the selected target species associated with *C. echinatus* when planted in Cenchrus-infested and Cenchrus-free soils. .

3. Discussion

The present investigation showed that the patches of the gardens and parks where the alien *Cenchrus echinatus* was recorded attained lower cover of the native species. This result significantly suggests the negative impact of such exotic species under field conditions. Maybe this is one of the important interesting findings of this study. This observation was similar to that obtained by Hassan and Mohamed [3] who explained the negative effect of naturalised alien *Paspalum dilatatum* on the native urban vegetation. What we found in this study was the existence of viable/germinable seeds of different native species in the soil under *C. echinatus*. It is also worth mentioning that those species were completely absent in the above-ground vegetation in the locations where their seeds were found. This result substantially reflects the negative effect of dense-cover of the exotic plant on seed

germination of the native ones. Consequently, reduction in cover of the native species may be related to decreased seed germination. On the other hand, the measured floristic diversity in this work was density dependent. In addition, the negative correlation between the cover of *C. echinatus* and the measured diversity indices was significant. In this regard, it was reported that interference effect of *C. echinatus* was higher as the density of this weed increases [43]. Germination may be delayed or completely inhibited due to the interspecific neighborhoods [44]. Besides, the negative density-dependent germination was observed by several authors e.g., [45,46].

Allelopathy may have role in weed interference and declining species diversity [47]. Moreover, naturalised alien plants may exert an allelopathic effect that inversely affects cover of the associated species [3,48]. This work showed that the soil under *C. echinatus* had no effect on germination and growth performance of the target species. This result suggests that allelopathy, as an interference mechanism, is not likely affecting cover and diversity of the native species and, consequently, it is difficult to claim that reduction in these criteria in the native plants in the sites comprising *C. echinatus* was attributed to allelopathy. This result substantially does not obey our hypothesis about the allelopathic potential of this species.

Our findings showed that some species were more affected by coexistence of the alien species in comparison with others. In particular, the results indicated that *Dactyloctenium aegyptium* was completely displaced from the sites involving *C. echinatus*. In addition, *Euphorbia peplus* was highly suffering. This effect could be attributed to rarity of these species. It was shown that rarer species were subjected to more suppression by the community dominants than the introduced grasses [49]. In addition, Zhang and van Kleunen [9] concluded that common naturalised alien species were more competitive than rare native species, and this might lead to loss of rare native species. Furthermore, our field observations indicated the tendency of the alien species to prevail, resulting more inhibition for the native ones. Existence of both native species in the seed bank suggests the inhibitory effect of *Cenchrus* on germination of these species. Complete displacement of *D. aegyptium* may be related to the complete inhibition of its seed germination exerted by the alien species under field conditions. Its existence in the seed bank, but its absence in the standing vegetation, suggests the inability of this species, in particular, to cope with conditions of the above-ground vegetation [50], maybe exerted by the dense cover of the alien species.

One of the most remarkable results was the effect of *C. echinatus* on soil properties. This study revealed that the sites comprising this species were of lower soil macronutrients, particularly available N, P and K. Such result could reflect the heavy removal of these nutrients made by *C. echinatus* over the native species. This effect may explain why cover and diversity of native vegetation were declined. Nutrient deficiency may lead to reduction in the overall biodiversity [51]. Furthermore, high plant diversity could be associated with high levels of soil macronutrients [52,53]. On the other hand, this result may also show the better competitive ability of such alien species compared with the native plants. This connotation may be in agreement with that obtained by Tecco et al. [54] who showed a superior competitive ability of alien species over that of natives is often associated with a high ability to acquire and retain resources. Moreover, exotic plants may show better competitive ability than native ones [55].

4. Materials and Methods

4.1. Vegetation Survey

A field study was conducted in the study area described by Hassan [24] during 2018-2019 and repeated in 2021-2022 growing seasons. A total of 80 plots, each of 10 × 1 m, were randomly sampled from the vegetation representing the gardens and parks in the study area. Amongst them, 40 plots were chosen in the sites with *C. echinatus* (the invaded plots), whereas the remaining plots were selected in the *Cenchrus*-free sites (control plots). On average, the control plots were selected about 5 m apart from those comprising *C. echinatus* to be sharing similar environmental conditions. The total number of plots selected was proportional to the area occupied by this alien weed. Plot size was selected on a basis of a similar study performed in this area [25]. In each plot, the names of all species

determined were listed. Species identification and nomenclature were carried out using Boulos [32–35]. The covering area of the species (expressed as m²) was virtually determined, and the relative cover of each species (p_i) (expressed as %) was calculated through the equation: relative cover = [cover of a species i / cover of all species] \times 100. Besides, the floristic diversity was measured as four diversity indices: species richness (S), i.e. the total number of plant species observed, Shannon-Wiener index (H'), Evenness index (E) and Simpson's index (D) [36,37] as follows:

$$H' = - \sum (p_i \times \ln p_i)$$

$$E = [-\sum (p_i \times \ln p_i)] / \ln S$$

$$D = 1 / C \text{ and } C = \sum p_i^2$$

4.2. Soil Seed Bank Sampling

The soil seed bank was sampled in the stands representing dense cover of *C. echinatus* (cover of *Cenchrus* \geq 70 % and the remaining vegetation was covered by the cultivated *Cynodon*) to avoid existence of seeds of other species from the above-ground vegetation, and to ascertain that the inhibition of germination of the detected seeds could be attributed to presence of the alien species. At such cover %, reduction in plant diversity was highly apparent. Four soil samples each at 5 cm depth were randomly collected from the upper 5 cm of soil around representative individuals from the stands with *Cenchrus*, while control soils were selected from the stands without *Cenchrus*. This depth was considered as most seeds have high tendency to be located at this depth [38]. Soil samples were sieved through a 2 mm sieve to remove plant litter. Known volumes of sieved soil samples were spread randomly in a 2 cm layer overlying sterilized soil in 10 cm \times 12 cm pots in a greenhouse sharing the prevailing environmental conditions at Beni –Suef University and regularly irrigated. Control pots contained the soils free from *Cenchrus* for a potential comparison with the seeds detected in *Cenchrus*-infested soils. The germinable/viable seeds were assessed by monitoring the seedling emergence. Emerging seedlings were counted and left to be juvenile for possible identification by the mentioned Boulos handbooks.

4.3. Soil Analysis

From each plot, three soil samples were collected from 0–20 cm depth and pooled together forming one composite. They were air dried, sieved through 2 mm sieve and stored in plastic bags for analysis. Determination of soil texture, pH, electrical conductivity (EC), and the contents of CaCO₃, organic carbon (OC) and availability of some nutrient including N, P, K and Zn was performed.

For determination of soil texture, i.e. the percentage of sand, silt and clay in the inorganic fraction of soil, the hydrometer method was followed [39]. Both pH and EC were measured in soil-water extract using deionized water. Soil pH was measured in the soil extract (1:2.5 w/v) with a digital pH meter (AD 3000), while EC was measured in another soil extract (1:5 w/v) using a conductivity meter (Jenway 3305). The soil content of CaCO₃ was estimated using the titration method [40]. Soil organic carbon was measured using Walkley and Black's method [41]. The available soil nutrients including nitrogen, phosphorus, potassium, zinc and copper in the soil samples were determined using Allen's methods [42].

4.4. Allelopathic Potential of *C. echinatus*

4.4.1. Soil Sampling and Preparation

Soil samples from the rhizosphere of *C. echinatus* in *Cenchrus*-dominating plots were collected and exposed to effective shaking inside a plastic bag to get one composite as the treatment soil (the invaded soil). The non-rhizosphere soil samples (control soil) were collected from the sites dominated by Bermuda grass (*Cynodon dactylon*); the native species cultivated in these gardens and parks for the greening purpose. Both soil types were sieved (2 mm size) to remove the plant litter and placed in

plastic pots (10 cm diameter × 15 cm depth each) for near sowing of the target species. Each pot contained about one kg of air-dried soil.

4.4.2. The Target Species

Three native target species namely: *Amaranthus viridis* (Linn.), *Dactyloctenium aegyptium* L. Willd. and *Eragrostis pilosa* (L.) P.Beauv. were used as test species. These species are common weeds in the study area [25]. The preliminary field observation showed that *D. aegyptium* appeared to have been away/apart from the sites with *C. echinatus*, whereas the remaining species had lower cover in these sites in comparison with the *Cenchrus*-free areas. This observation may reflect the impact level of the alien species. Ripe seeds of these species were collected from different locations constituting the gardens and parks of the study area (i.e. the New Beni-Suef city) at the late fruiting stage.

4.4.3. Test for Allelopathy

Thirty seeds of the target species were equally disseminated at 0.3 cm depth of soil per pot. The pots were irrigated regularly via misting process when need. The experiment was retained in a protected site under the prevailing environmental conditions in a completely randomized design with four replicates for 30 days. At the end of the test, the numbers of emerging seedlings were determined to calculate the germination percentage. Growth criteria including shoot height, root depth and the total biomass were measured per each individual as indicated by Hassan and Mohamed [3].

4.5. Statistical Analyses

The data were first checked for normality and homogeneity of variances using the Kolmogorov–Smirnov and Levene's tests, respectively. The results meeting the requirement of normality and homoscedasticity were analysed using independent-samples T test. When field data were not normally distributed, the non-parametric Mann Whitney U test was performed. To evaluate a relationship between the cover of the exotic *C. echinatus* and the different diversity indices, a Pearson correlation analysis was carried out. All analyses were carried out using SPSS, version 20.0 (IBM Corporation, USA).

5. Conclusions

To great extent, the results of this study followed the main hypothesis proposed. Coexistence of the exotic naturalised *Cenchrus echinatus* in the urban vegetation led to remarkable decline in cover of most of the associated native plants. Rare species; particularly *Dactyloctenium aegyptium* and *Euphorbia peplus*, were more affected in comparison with the remaining native species. The adverse effect of this species on plant diversity varied with respect to the measured index and its cover value. Species richness was not affected at all, whereas the remaining indices were reduced at higher densities of the alien species. Moreover, all of these indices were inversely correlated with cover values of such plant. Interestingly, Presence of this alien species resulted in significant reduction in the available soil macronutrients including nitrogen, phosphorus and potassium. In addition, the soil under this species indicated the existence of germinable /viable seeds of some species which were absent from the standing vegetation. However, the rhizosphere soil under this species had no effect on germination and growth performance of the native target species under greenhouse conditions. These results suggest the negative effect of the alien *C. echinatus* on the native species in the urban vegetation. Reduction in soil macronutrients may be attributed to heavy removal of these macronutrients made by *C. echinatus*. Besides, failure of germination of some native species in field may be attributed to the dense cover of *Cenchrus*. Consequently, the naturalised alien *C. echinatus* may be more competitor than the native ones. Allelopathic potential of such species seemed to be inactive mechanism affecting cover and diversity of native species. Till now, *C. echinatus* has not been recorded as an invasive one. However, its negative effects on the native vegetation and soil were addressed. This study substantially indicated that naturalised alien *C. echinatus* represents a threat

for the urban vegetation. Conservation strategies should be devoted to control alien species in the urban ecosystems.

Author Contributions: M.O.H.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, Wrote the paper. H.Y.M.: contributed in writing the manuscript. A.A.: Performed the experiments; Analyzed and interpreted the data; Wrote the manuscript. M.K.O. and B.H.K.: revised the manuscript and provided the funding agency. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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