Magna Scientia UCEVA (2023) 3:2, 165-174
ISSN: 2805-6884 e-ISSN: 2805-6701
https://doi.org/10.54502/msuceva.v3n2a6

Original Research Article | *Agricultural and Biological Sciences*

Seedling competition between *Pennisetum setaceum* (Poaceae) and three native weeds of La Primavera wood, Guadalajara, Jalisco (México)

Competencia entre la exótica *Pennisetum setaceum* (Poaceae) y tres herbáceas nativas del bosque La Primavera, Guadalajara, Jalisco (México) en semillero

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First draft submitted: 08-08-2023
Accepted for publication: 29-11-2023
Published on line: 01-12-2023

Key words:

Colonization; interspecific competition; desertification; invasive alien species; loss of biodiversity.

Palabras clave:

Colonización; competencia interespecífica; desertificación; especies exóticas invasoras; pérdida de biodiversidad.

Citation:

Bertolini V., Sedano Ibarra OA., Valle Mora JF.,Gallegos Rodríguez A., Hernández Álvarez E., Rojas Velásquez AN. Seedling competition between *Pennisetum setaceum* (Poaceae) and three native weeds of La Primavera wood, Guadalajara, Jalisco (México). *Magna Scientia UCEVA* 2023; 3:2 165-174. *https://doi.org/10.54502/msuceva.v3n2a6*

Abstract

Pennisetum setaceum (Forssk.) Chiov., 1923 is an exotic grass from the Arabian Peninsula that has been very successful as an ornamental plant worldwide in recent years. Unfortunately, it has proved to be a very competitive invader, causing ecological problems in several regions of the world. We don't know exactly how this species interacts with native weeds in Mexico. Our study aims to show the interactions of Pennisetum with three species of native weeds in the surroundings of the metropolitan area of Guadalajara, Jalisco, Mexico: *Aeschynomene villosa* var. longifolia (Micheli) Rudd, *Desmodium aparines* (Link) DC. and *Paspalum notatum* (Flüggé). The seeds of Pennisetum were tested in monospecific groups (competing against itself) and in association with each of the native species mentioned and with a treatment together with all the compound of the species mentioned, thus simulating what could happen in natural conditions upon the arrival of the seeds of *P. setaceum* in a degraded soil of Guadalajara. The results show how the biomass produced and the speed of growth of Pennisetum can be a real alarm for the conservation of local germplasm.

Resumen

Pennisetum setaceum (Forssk.) Chiov., 1923 es una gramínea originaria de la península arábiga que ha tenido mucho éxito como planta ornamental en las últimas décadas a nivel mundial. Desafortunadamente, de un punto de vista ecológico se ha demostrado ser una invasora muy competitiva, provocando invasiones consistentes en varias regiones del mundo. Poco se ha estudiado acerca de ella con respeto a su distribución actual en México y a sus relaciones de antagonismo con las especies nativas. Con el objetivo de analizar la competición entre ella y tres especies de herbáceas nativas de los alrededores de la zona metropolitana de Guadalajara, Jalisco, México (*Aeschynomene villosa* var. longifolia (Micheli) Rudd, *Desmodium aparines* (Link) DC. y *Paspalum notatum* Flüggé), se ha sembrado semilla de la especie a testar en grupos: monoespecífico (compitiendo contra ella misma); en asociación con cada una de las especies mencionadas y con un tratamiento junto con las 3 especies nativas al mismo tiempo, simulando así lo que pudiera pasar en condiciones naturales a la llegada de la semilla de *P. setaceum* en un suelo degradado de Guadalajara, México. Los resultados muestran como la biomasa producida y la velocidad de crecimiento de *P. setaceum*, pueden ser una alarma real para la conservación del germoplasma local.

Introduction

In Mexico, of the 1,100 exotic species that have been recorded, 348 are considered to be invasive, of which 200 are under surveillance by the authorities [1]. *P. setaceum* (Forssk.) Chiov., 1923 is included in the list of high-risk invasive exotics for Mexico by the Ministry of Environment and Natural Resources [2]. This agency records that until 2016 it was found in the states of Baja California, Sonora and Nuevo León. Currently, it is common to see it in cities such as Guadalajara, Mexico City, Querétaro, León Guanajuato, Puerto Vallarta, Tuxtla Gutierrez, among others (personal observation, unpublished data).

Pennisetum setaceum, a member of the Poaceae family, has shown a remarkable propensity for aggressive colonization following its introduction as an exotic ornamental or forage species in various regions of the world [3]. Native to North Africa, East Africa and the Arabian Peninsula [4], especially on the arid coasts and pre-desert areas of the Sahara [5]. Nowadays, it can be considered a cosmopolitan species, distributed on almost all continents. It benefits from a wide climatic range below 1,270 mm of annual rainfall and above 0°C [6].

It adapts to degraded and poor soils and arid climates and has become invasive in several countries, reducing biodiversity, impoverishing soils and displacing native grasses [7]. *P. setaceum* is highly resilient to the passage of fire due to its resistant root system and the rapid germination of its seeds after burning [8]. Its ability to adapt easily has threatened biodiversity in several natural areas around the world. For example, tropical dry forests in Hawaii have been affected [9,10], it competes with the native grass *Heteropogon contortus* (L.) P. Beauv. former Roem. and Schult. because it uses water and light more efficiently and produces more biomass [2]. The Mediterranean coasts of Spain and Italy are suffering from a very noticeable invasion at the moment [6,7].

Currently, *P. setaceum* is considered one of the major causes of conversion of tropical dry forests to monospecific grasslands, along with soil use conversion, grazing and logging [11]. This trait makes the species invasive, capable of altering the ecology of the colonised area [12]. In Italy, the seedbed development of *P. setaceum* has been compared with the native *Ampelodesmos mauritanicus* (Poir.) T. Durand & Schinz, showing that the invasive species synthesises biomass faster than the native species [13]. In general, the Poaceae family has been shown to be highly competitive for water and nutrients, exhibiting strong interspecific competition and allelopathy [14].

Little research has been carried out in Mexico on the ecology of *P. setaceum* and its interaction with native grasses or herbaceous species in general, and it is believed that its spread could threaten local ecosystems. On the contrary, native herbaceous species have been shown to be of great ecological importance [15], and help counteract soil degradation by improving soil quality, as they are nitrogen-fixing plants, retain substrate, prevent sedimentation and compaction [16]. Romo-Campos et al. [17], studying some degraded forest slopes in the La Primavera Flora and Fauna Protection Area (APFFLP), mention that the use of native herbaceous plants with different biological traits, can accelerate the plant succession process, recovering the functional and structural characteristics of the soils. Experimentally, physical or chemical scarification is usually used to induce homogeneity in seed germination [17], especially in the Fabaceae family, which have a period of dormancy [18]. It has also been documented that the length of time the seed is stored can be the key to increasing the germination percentage in some species [19].

Unlike native species, *P. setaceum* can germinate under much harsher conditions and prefers poor soils, depleting them even more of moisture and minerals and tending to produce monospecific meadows [12,13]. Therefore, the potential colonization of certain degraded slopes within the APFFLP, a vital green enclave in the metropolitan expanse of Guadalajara-Mexico, poses an immediate risk of exacerbating desertification and environmental impoverishment. Furthermore, this encroachment poses an increased threat of increased fire risk in the area. This study aims to comprehensively investigate and contrast the germination and seedling development dynamics of the exotic species with those of three native herbaceous species of Jalisco (two from the Fabaceae family and one from the Poaceae family). The study will be carried out under controlled conditions that simulate both intra- and interspecific competition, using alveolar seedbeds to unravel the intricacies of these ecological interactions.

Methods

The experimental set-up started on 1 October 2021 in the controlled environment of the greenhouse located at the Seeds Department of the University Centre for Biological and Agricultural Sciences (CUCBA) of the University of Guadalajara, Mexico. The experiment was continuously monitored until 24 February 2022. The soil used in the study came from the La Primavera Forest Flora and Fauna Protection Area (APFFLP) in Guadalajara, Mexico, specifically from a section of road affected by a landslide. This soil, which was virtually untouched by plant species and had a low organic matter content, was sterilised in an autoclave before use.

The experiment used three alveolar polystyrene seedbeds, each containing sockets measuring 4 cm by 4 cm by 10 cm in depth, giving a total of 60 pots per seedbed. Treatment allocations were randomised across these three seedbeds and each treatment was represented by 16 replicates. Within each replicate, a total of 20 seeds were sown in a single cavity. The experimental design, including treatment allocation, is summarised in table 1 for clarity and reference.

Table 1. Scheme of treatment

Treatment†	Species	Replicates	Total number of seeds per replicate
C0	*Pennisetum setaceum*	16	20
C1	*Aeschynomene villosa*	16	20
C2	*Desmodium aparines*	16	20
C3	*Paspalum notatum*	16	20
T1.0	*P. setaceumn* vs *A. villosa*	16	10
T1.1	*A. villosa* vs *P. setaceum*	16	10
T2.0	*P. setaceum* vs *D. aparines*	16	10
T2.1	*D. aparines* vs *P. setaceum*	16	10
T3.0	*P. setaceum* vs *P.notatum*	16	10
T3.1	*P. notatum vs P. setaceum*	16	10
T4.0	*P. setaceum vs (A. villosa + D. aparines + P. notatum)*	16	5
T4.1	*A. villosa vs (D. aparines + P. notatum + P. setaceum)*	16	5
T4.2	*D. aparines vs (A. villosa + P. notatum + P. setaceum)*	16	5
T4.3	*P. notatum vs (A. villosa + D. aparines + P. setaceum)*	16	5

†= The replication coincides with one alveolus of the tray: the total number of seeds was always kept at 20. By interacting different species, a total number of seeds equal to 10 per species, was occupied for each replicate (alveolus) when the total number of species was 2 per treatment (treatments T1, T2 and T3); when the four species, were made to interact in the same physical space (alveolus), five seeds per species, were used per replicate (treatment T4).

Seeds of *P. setaceum* were meticulously collected between April and September 2021, harvested from spikelets of spontaneously growing plants within the metropolitan area of Guadalajara-Mexico to ensure regional viability. The procurement of botanical specimens and seeds of native herbaceous species, took place between September and November 2020 within the APFFLP. Following established protocols by Lot and Chiang [20], the collected species were meticulously herbarised and subsequently identified at the family level using botanical keys. A comparative analysis was carried out with the herbarium specimens of the Institute of Botany of the University of Guadalajara (IBUG), where the specimens were deposited for reference.

Seeds of *Aeschynomene villosa* var. longifolia (Micheli) Rudd, *Desmodium aparines* (Link) DC. and *Paspalum notatum* Flüggé, were methodically collected from the ripe fruits of at least 10 adult individuals. The fruits were then dried and cleaned, the seeds manually extracted and carefully preserved in brown paper bags. These seeds found a safe harbour in the seed laboratory of the University Centre for Biological and Agricultural Sciences (CUCBA), where they were stored at room temperature (25°C).

Viability tests

Seed viability was quantified using the tetrazolium (2,3,5-triphenyltetrazolium chloride) test as described by Maldonado-Peralta et al. [21]. For each species, 30 seeds were analysed in petri dishes coated with a 0.1% solution of tetrazolium (2,3,5-triphenyltetrazolium chloride) [22]. These prepared seeds were then incubated in a germination chamber (SEEDBURO, MPG1000) at a controlled temperature of 25ºC in the dark for 24 hours. After this incubation period, the tetrazolium solution was carefully removed with distilled water. Seed viability was then assessed using a stereoscopic microscope (VELAB, VE-S3) according to ISTA standards [23]. The grading system was based on the colouration of the embryo according to established criteria. Seeds with colours ranging from deep red to pink were considered viable, while those with no or only partial colouration were considered non-viable. This careful assessment provided a comprehensive understanding of the viability status of each set of seeds.

For *P. setaceum* seeds, in addition to the tetrazolium test, germination was checked in a Petri dish with moist paper in the dark and at a constant temperature in a germination chamber (SEEDBURO, MPG1000) for a period of 3 days. In the case of *P. setaceum*, no type of scarification or pregermination treatment was necessary due to the high percentage of germination in the viability test. In the case of the native seeds, *A. villosa*, *D. aparines* and *P. notatum*, a pregerminative treatment was used to ensure the highest percentage of germination, scarifying with a small cut with pliers in their outer layer, given the latency of the species used [24].

Experiment maintenance and response variable analysis

The number of plants was counted every 15 days in order to monitor the emergence process of the seedlings, to record the germination dynamics over time and the possible loss of individuals within each replicate. During the experimental period, the plants were watered two to three times a week, with a total of 4 litres per watering, without any fertilisation. The greenhouse used is a cold greenhouse with no artificial heating, which provided ideal climatic conditions for germination, plant growth and protection from the elements during the observation period.

At the end of the 5-month experimental period from sowing, a comprehensive analysis of response variables was conducted to elucidate biological interactions and competitive dynamics, with a particular focus on seedling growth and nutrient uptake. Using R software [25,26], the study included several key parameters: number of plants per treatment (Num_plant), number of leaves per plant (Num_leaves), number of main roots per plant (Num_roots), stem length (height) (Stem_length), root length (root lenght), fresh weight (Fresh_weight) and dry weight (Dry_weight). Macro- and microelements were analysed after the plant samples were weighed and dried (ADVENTURE balance, OHAUS; FELISA drying oven).

Nutrient analysis

The nutritional assessment of both soil and plant samples was carried out at the Environmental Laboratory of Organic Fertilisers within CUCBA (UDG). As a crucial benchmark to determine the effect of treatments on mineral uptake by plants, a soil sample from untreated conditions (consisting of empty plots without planting) was meticulously analysed at the culmination of the experimental trial. This analysis included a comprehensive examination of the physico-chemical characteristics as well as the quantification of macro- and micro-elements. The inclusion of this reference control provided a basis for evaluating and contextualising the observed effects on nutrient dynamics within the experimental context. A composite plant sample and a composite soil sample were taken from each treatment. The composite soil samples corresponding to each treatment weighed 800 g each. For both plant and soil samples, three measurements were taken and averaged.

Statistical analysis

The statistical analysis applied to the response variables was a canonical multivariate analysis of variance, as the measured response variables are correlated. Multiple comparisons are made using the 95% confidence intervals of the first two canonical variables. A generalised linear model with binomial response was performed to compare between treatments, based on the Num_plan response. Multiple comparisons were then performed using orthogonal contrasts with Bonferroni correction.

Results

Viability tests

The seeds of the native species showed tetrazolium viability percentages of approximately 85% after 24 hours and a germination rate of 70% after 48 hours in a Petri dish with moistened paper, following the manual scarification procedure described above. In contrast, *P. setaceum* seeds had a tetrazolium test positivity of 87% after 24 hours and a germination rate of 76% after 48 hours in a Petri dish with moistened paper. These results underline the nuanced differences in viability and germination dynamics between the native species and *P. setaceum* under the specified experimental conditions.

Response variable analysis

Canonical multivariate analysis of variance yielded significant results ($F=11.623$; $df=91.1470$; p-value=2.2e-16) based on the measured response variables in the plants. Subsequent canonical analysis indicates that treatments T1.0, T2.0, T3.0, T3.1, T4.3, T1.1, C1 and C2 are statistically equivalent, while the remaining treatment combinations show statistical differences. In particular, treatments T1.0, T2.0, T3.0 and C0, are characterised by a greater number of roots, a higher dry and fresh weight, an increased stem length, a higher number of leaves and a longer root length compared to the other treatments. These treatments include controls exclusively with *P. setaceum* (C0), reflecting intraspecific competitiveness, and the same with all interactions except with the full set of native species, reflecting interspecific competitiveness. The treatments associated with the highest number of plants are T1.1, C2 and C1, as shown in figure 1.

Figure 1. Evaluation of the response variables at the end of the experimental test

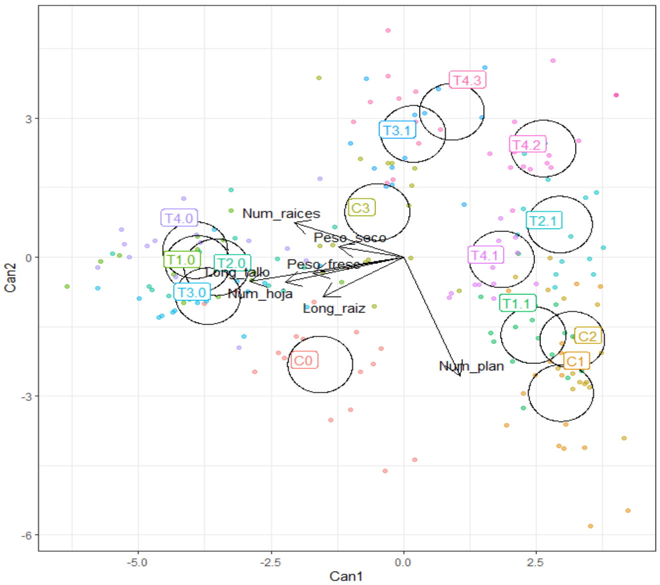


Figure 2, illustrates the dynamics of the intraspecific competitiveness treatments, specifically the control treatments (C0, C1, C2 and C3), including *A. villosa* (C1), which consistently produces the highest number of individuals in all treatments. *A. villosa* maintains its dominance by consistently producing the maximum number of individuals in all treatment scenarios. Conversely, *P. notatum* (C3) consistently records the lowest number of individuals, reaching a minimum in the interaction with all four species (i.e. treatment T4).

When examining variables such as number of leaves and roots in intraspecific interactions (within the same species), *P. notatum* records the highest values. However, in interspecific interactions, *P. setaceum* consistently records higher values for both variables. This is true whether *P. setaceum* competes with a single species or simultaneously with all three species (as observed in treatment T4), as shown in figure 2.

With respect to the variables stem length and average root length per plant, *P. setaceum* shows consistently higher values compared to the three-native species. This trend is evident both in intraspecific competition scenarios (C0) and when *P. setaceum* competes with a single species or all three native species simultaneously (T1, T2, T3 and T4) (see figure 3).

Figure 2. Behaviour of the response variables with respect to number of plants (Num_plants), number of leaves per plant (Num_leaves) and number of roots per plant at the end of the experiment (5 months after sowing).

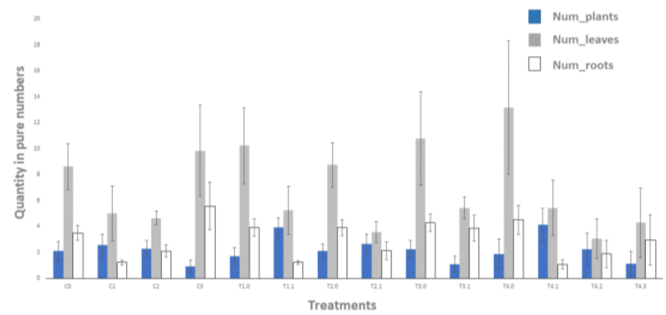
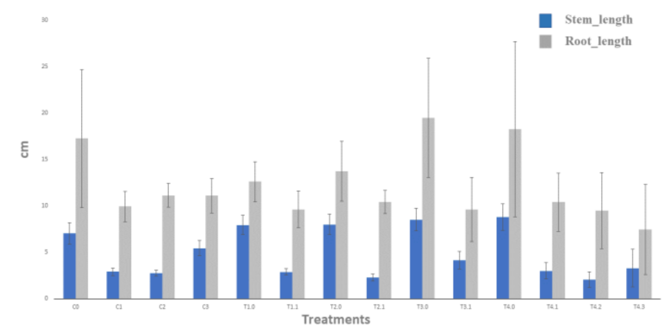


Figure 3. Behaviour of response variables relating to stem length per plant (Stem_lenght) and root length per plant (Root_lenght) at the end of the trial (5 months after sowing)

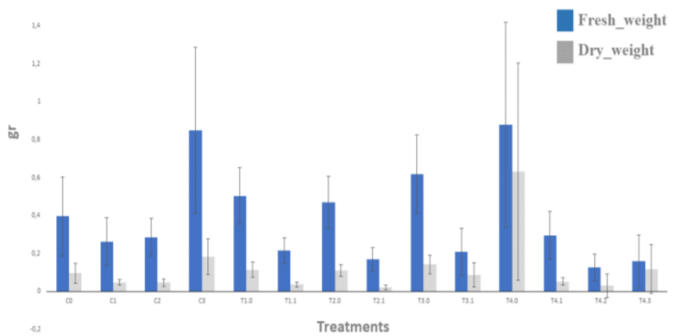


On the other hand, *P. notatum* reaches maximum values for fresh weight and average dry weight per plant when it does not interact with other species, specifically in intraspecific competition (C3). *P. setaceum* follows a similar pattern under intraspecific conditions (C0). However, when interactions are taken under consideration, particularly with regard to these two variables, *P. setaceum* undergoes a reversal and registers higher values. In particular, the maximum values are obtained in the interaction with the three-native species (T4), exceeding the maximum values recorded for *P. notatum* in the control treatment (C3) (see figure 4).

Nutrient analysis

It was observed that most of the treatments have an N content around 3000 to 3800 $mg.kg^{-1}$. For P content, treatment C2 is numerically higher than the other treatments. For the K content, treatments C2, T2-1 and T42 showed the highest values above 2500 mg.kg^{-1}. For Ca and Mg, treatments C2, T1-1, T2-1, T41 and T42, showed the highest contents of these elements. Na accumulation was also observed, with a maximum in treatment T2-1.

Figure 4. Behaviour of response variables in relation to fresh weight per plant (Fresh_weight) and dry weight per plant (Dry_weight) at the end of the trial (5 months after sowing).



Copper (Cu), showed a comparatively low content among the microelements, with similar values in the different treatments. Manganese (Mn) showed the highest values in treatments T1 and T4, approaching 200 mg.kg^{-1}. Iron (Fe), emerged as the microelement with the highest accumulation in plants, with peak values observed in treatments C1 and T1-0, ranging from 1300 to 1400 mg.kg^{-1}. In the case of zinc (Zn), the majority of treatments did not exceed 200 mg.kg^{-1}, except for treatments C1, T1-1 and T4-1, which exceeded this threshold (see table 2).

The soil analysis of the untreated control treatment, shows the presence of a regosol characterised by calcareous gravel and sandy loam texture, containing 0.13% organic matter and having a neutral pH. The predominant cations in the soil are sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg), as shown in table 3. Among the macroelements, calcium (Ca) and potassium (K), have the highest concentrations, ranging from 600 to 750 mg.kg^{-1} and 600 mg.kg^{-1} respectively, followed by magnesium (Mg) with a content of 150 mg.kg^{-1}. Nitrogen (N) and phosphorus (P) are relatively low, not exceeding 50 mg.kg^{-1}. Among the microelements, iron (Fe) stands out with values between 7 and 12 mg.kg^{-1}, followed by manganese (Mn) and zinc (Zn) with values below 2 mg.kg^{-1}. Copper (Cu) is almost absent in the soil, with values close to 1 mg.kg^{-1}, as shown in table 4.

Table 2. Macro- and microelements in foliar diagnosis

Treatments	Macroelements				
	N	P	K	Ca	Mg
C0	3690	175.9	1542.2	204.2	203.8
C1	2970	251.7	1845.4	508	231.7
C2	3640	860.0	2653.9	793.8	327.5
C3	3150	176.7	1836.3	416.9	207.4
T1-0	3190	243.6	1476.1	157.7	196
T1-1	3460	290.4	1742.6	642.5	250.1
T2-0	3270	394.1	1638.7	172.2	197.9
T2-1	3480	196.7	3007.5	769.8	365.8
T3-0	3290	212.7	1569.8	143.5	191.1
T3-1	3270	182.8	1867.7	309.8	165.4
T4-0	3360	251.6	1654.9	137.3	185.1
T4-1	3470	339.2	2133.8	651.9	260.2
T4-2	3890	188.2	2863	835.8	345
T4-3	3110	206.1	2071.7	387.7	216.4
Treatments	**Microelements**				
	Cu	**Mn**	**Fe**	**Zn**	**Na**
C0	22.3	98.5	705.6	95.7	469.5
C1	31.7	200.5	1410.2	211.9	557.2
C2	29.9	166.3	909.7	193.1	676.4
C3	35.7	94.7	1121.6	125.2	664.3
T1-0	30.9	123.3	1310.4	101.1	510
T1-1	31.6	178.6	947.5	206.6	518.6
T2-0	45.7	120.1	654.6	140.6	538.6
T2-1	28.1	149.7	569.7	192.9	833.1
T3-0	26.6	118.3	751.7	134.7	503.4
T3-1	28.9	95.1	513.8	139.4	427.4
T4-0	32.7	100.9	785.7	102.1	399
T4-1	23	203.6	749.3	217.4	430.3
T4-2	20.2	165.6	463.7	175.1	539.6
T4-3	33.4	114.3	397.5	170.6	656.5

†= Measurements are expressed in mg.kg^{-1}

Table 3. Soil analysis on a sample of control soil obtained from the alveoli of the polystyrene tray, without any species planted, 5 months after the start of the experiment

Determination	Method	Result
Soil organic matter (%)	Walker & Black	0.13
Cation Exchange Capacity (CEC) meq.100g^{-1}	Ammonium acetate	8.42
Soil texture	Boyoucus	Sand-loamy soil
Sand%		79
Clay%		5.72
Loam%		15.28
Nutrients		
N-No$_3$ ppm	Acetylsalicylic acid	4.1
Phosphorus ppm	Bray	2.8
Potassium ppm	Acetate	623
Sodium ppm	Acetate	842
Calcium ppm	Acetate	442
Magnesium ppm	Acetate	115
Copper ppm	DTPA	0.37
Manganese ppm	DTPA	2.17
Iron ppm	DTPA	12.24
Zinc ppm	DTPA	1.63
Exchangeable cations		
Potassium meq.100 g^{-1}	Acetate	1.6
Sodium meq.100 g^{-}	Acetate	3.66
Calcium meq.100 g^{-}	Acetate	2.21

Table 3. Continuation

Determination	Method	Result
Exchangeable cations		
Magnesium meq.100 g^{-1}	Acetate	0.95
pH1-2	Potentiometer	7.14
Electrical conductivity ($mmhos.cm^{-1}$)	Conductimeter	0.1

Table 4. Comprehensive elemental analysis of soils across treatment variations†: Macro- and microelement profiling

Treatments	Macroelements				
	NO_3	P	K	Ca	Mg
C0	41.3	2.8	623	442	114
C1	38.5	1.04	620	444	117
C2	27	1.67	353	385	107
C3	62	1.18	439	599	148
T1	34.1	1.50	357	416	105
T2	20.7	1.06	395	539	118
T3	35.5	1.21	336	765	129
T4	23.4	1.47	368	532	145
Treatments	**Microelements**				
	Cu	Mn	Fe	Zn	Na
C0	0.37	2.17	12.24	1.63	842
C1	0.18	1.82	10.75	1.62	893
C2	0.13	1.81	12.92	1.63	414
C3	0.13	1.45	7.1	1.48	566
T1	0.27	2.23	10.5	1.15	470
T2	0.27	1.8	9.19	1.66	544
T3	0.25	1.51	10.62	1.45	464
T4	0.25	1.77	12.79	1.63	515

†= Measurements are expressed in $mg.kg^{-1}$

Discussion

The analysis carried out in this study shows that, although *P. setaceum* does not have the highest germination rate, its remarkable ability to optimise limited resources and promote substantial development, as evidenced by the synthesis of greater biomass, is evident. The nitrogen (N) content in most of the plants used in the experiment was above 3%, with the exception of treatment C1, where it reached 2.97%. In particular, the nitrogen concentrations observed are in line with the results obtained by Howeler [27] for grasses, who reported values of 2.45%. The observed pattern of uptake of this nutrient is consistent with its greater importance in the youngest parts of the plant, as it is less critical in older parts. This is supported by the assertion of Norton [28], that the presence of nitrogen in plant tissues decreases with the age of the plant, which is attributed to the reduction in the leaf to stem ratio as the plant matures.

In the interaction treatments, the presence of *P. setaceum* significantly constrained the growth of other species, leading to reduced biomass production both within *P. setaceum* itself and in the absence of interaction with it. This phenomenon is consistent with the observations of Hooper et al. [15], who demonstrated that highly competitive herbaceous plants, have a limiting effect on the growth and biomass synthesis of less competitive species. In addition, Poaceae generally show a strong competitive advantage over Fabaceae.

Furthermore, it is evident that herbaceous plants tend to allocate resources towards denser root systems and reduce stem development in order to effectively use limited resources in degraded soils [29-31]. In this context, the physiological response is particularly pronounced in *P. setaceum*, which exhibits extensive root development compared to its counterparts. This adaptive strategy allows *P. setaceum* to effectively accumulate a larger reservoir of water and nutrients [6].

Mayo-Mendoza et al. [16] have claimed that Fabaceae species, including *D. aparines*, are emerging as highly suitable candidates for soil restoration in degraded environments. However, the potential invasion of *P. setaceum* in these areas, raises concerns, as it could emerge as a formidable competitor to native pioneer herbaceous species, thereby jeopardising the ecological equilibrium of the protected natural area, a phenomenon observed in different regions worldwide [6,16].

Conclusions

After a thorough review of previous research and drawing lessons from global experience of the spread and invasion of *P. setaceum*, the initial findings presented in this study demonstrate the strong competitive potential of the grass and pose a significant invasion risk. The empirical evidence highlights how *P. setaceum* outcompetes native spring forest grasses in biomass production under degraded soil conditions, signalling a potential catalyst for severe invasion, posing a significant threat to local biodiversity and increasing the risk of wildfire.

While this study provides a basic understanding of the invasive potential of *P. setaceum*, it falls short of unravelling the full complexity of biological interactions between this grass and native Mexican species. It serves as a first step towards a comprehensive, science-based understanding of biological invasion. In addition, the nutritional aspects of *P. setaceum* remain relatively unexplored, highlighting the need for further investigation of this physiological dimension. This study thus, provides a concrete baseline for future research efforts to better understand the complex dynamics of *P. setaceum* interactions with native species in Mexican territory, providing a platform for informed conservation strategies and sustainable land management practices.

Acknowledgements

This work was supported by the National Council of Humanities, Science and Technology of Mexico (CONAHCYT) [Grant numbers: I1200/224/2021]. We also acknowledge the collaboration of the Environmental Department of the Municipality of Zapopan and the landscape architect Oscar Jauregui Ortiz.

Consent for publication

The authors read and approved the final manuscript.

Competing interest

The authors declare no conflict of interest. This document only reflects their point of view and not that of the institution to which they belong.

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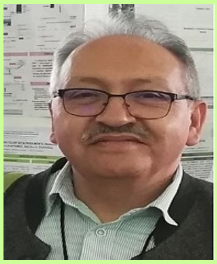

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References

[1] Comisión Nacional para el Conocimiento y Uso de la Biodiversidad-CONABIO. Especies exóticas invasoras 2021. https://www.biodiversidad.gob.mx/especies/Invasoras/cuales-son

[2] Secretaría de Medio Ambiente y Recursos Naturales-SEMARNAT. Anexo I: listado de plantas Lista de especies exóticas invasoras para México. Gobierno de México 2017. https://www.gob.mx/semarnat/documentos/listado-de-plantas

[3] Global Invasive Species Database-GISD. Species profile: *Cenchrus setaceus* 2010. https://www.iucngisd.org/gisd/species.php?sc=309

[4] Brunel S, Branquart E, Fried G, van Valkenburg J, Brundu G, Starfinger U, et al. The EPPO prioritization process for invasive alien plants. Bulletin 40 OEPP/EPPO. 2010. https://www.eppo.int/media/uploaded_images/ACTIVITIES/invasive_plants/Brunel_et_al-2010-EPPO_Bulletin.pdf

[5] Williams DG, Mack RN, Black RA. Ecophysiology of Introduced *Pennisetum setaceum* on Hawaii: The Role of Phenotypic Plasticity. Ecology 1995;76:1569–80. https://doi.org/10.2307/1938158

[6] Pasta S, Badalamenti P, La Mantia T. Tempi e modi di un'invasione incontrastata: *Pennisetum setaceum* (Forssk.) Chiov. (Poaceae) in Sicilia. Naturalista Siciliano 2010;IV:487–525. https://www.sssn.it/PDF/PDF%20NS%2034/487-526.pdf

[7] Da Re D, Tordoni E, De Pascalis F, Negrín-Pérez Z, Fernández-Palacios JM, Arévalo JR, et al. Invasive fountain grass (*Pennisetum setaceum* (Forssk.) Chiov.) increases its potential area of distribution in Tenerife island under future climatic scenarios. Plant Ecol 2020;221:867–82. https://doi.org/10.1007/s11258-020-01046-9

[8] Cabrera-García P, Marrero MD, Benítez AN, Paz R. Valorization of *Pennisetum setaceum*: From Invasive Plant to Fiber Reinforcement of Injected Composites. Plants 2023;12:1777. https://doi.org/10.3390/plants12091777

[9] Tunison J. P. setaceum control in Hawaii Volcanoes National Park: management considerations and strategies . In: Stone C, Smith C, Tunison J, editors. Alien Plant invasions in native ecosystems of Hawai'i: management and research. 1st ed., Honolulu, Hawai: University of Hawai'i Press; 1992, p. 376–93.

[10] Wagner W, Herbst D, Sohmer S. Manual of the flowering plants of Hawaii. 1st ed. Honolulu, Hawai: University of Hawaii Press; 1990.

[11] Williams DG, Black RA. Drought response of a native and introduced Hawaiian grass. Oecologia 1994;97:512–9. https://doi.org/10.1007/BF00325890

[12] Cordell S, Sandquist DR. The impact of an invasive African bunchgrass (*Pennisetum setaceum*) on water availability and productivity of canopy trees within a tropical dry forest in Hawaii. Funct Ecol 2008; 22:1008–17. https://doi.org/10.1111/j.1365-2435.2008.01471.x.

[13] Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ. Naturalization and invasion of alien plants: concepts and definitions. Divers Distrib 2000;6:93–107. https://doi.org/10.1046/j.1472-4642.2000.00083.x

[14] Badalamenti E, Militello M, La Mantia T, Gugliuzza G. Seedling growth of a native (*Ampelodesmos mauritanicus*) and an exotic (*Pennisetum setaceum*) grass. Acta Oecologica 2016;77:37–42. https://doi.org/10.1016/j.actao.2016.08.013.

[15] Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, et al. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol Monogr 2005; 75:3–35. https://doi.org/10.1890/04-0922

[16] Mayo-Mendoza M, Romo-Campos R de L, Medina-Fernández P. Tasa relativa de crecimiento de herbáceas con potencial de restauración en suelos degradados del bosque La Primavera, Jalisco, México. Acta Univ 2018;28:58–66. https://doi.org/10.15174/au.2018.1930

[17] Rondón J, Vidal R. Establecimiento de la cubierta vegetal en áreas degradadas (principios y métodos). Revista Forestal Latinoamericana 2005;20:63–82. https://www.saber.ula.ve/bitstream/handle/123456789/24091/articulo4.pdf;jsessionid=C36AEBEC5F92CA8A078F57679C0CBAA8?sequence=2

[18] Finch-Savage WE, Leubner-Metzger G. Seed dormancy and the control of germination. New Phytologist 2006;171:501–23. https://doi.org/10.1111/j.1469-8137.2006.01787.x

[19] Flores J, Jurado E. Germinación de especies de cactáceas en categoría de riesgo del desierto chihuahuense. Rev Mex Cienc For 2011;2:59–70. https://www.scielo.org.mx/pdf/remcf/v2n8/v2n8a6.pdf

[20] Lot A, Chiang F. Manual de Herbario. Administración y manejo de colecciones, técnicas de recolección y preparación de ejemplares botánicos. 1st ed. México DF, México: Departamento de Botánica, Instituto de Biología, UNAM. Consejo Nacional de la Flora de México, A. C. México.; 1986.

[21] Maldonado-Peralta MA, De Los Santos GG, García-Nava JR, Ramírez-Herrera C, Hernández-Livera A, Valdez-Carrazco JM, et al. Seed viability and vigour of two nanche species (*Malpighia mexicana* and *Byrsonima crassifolia*). Seed Science and Technology 2016;44:168–76. https://doi.org/10.15258/sst.2016.44.1.03

[22] Salazar Mercado S, Maldonado Bayona H, Quintero Caleño J. Evaluación de la calidad fisiológica de las semillas de *Linum usitatissimum* L. con la prueba de tetrazolio. Avances En Investigación Agropecuaria 2018;22:25–35. https://revistasacademicas.ucol.mx/index.php/agropecuaria/issue/view/27/55

[23] International Seed Testing Association-ISTA. International Rules for Seed Testing. Seed Health Methods 2024. https://www.seedtest.org/en/international-rules-for-seed-testing/seed-health-methods-product-1054.html

[24] Romo Campos R, Contreras Rodríguez S, Huerta Martínez F, Muñoz Urías A. Efecto del vermiabono en crecimiento y acumulación de biomasa en *Aeschynomene americana* L. en bancos de minería a cielo abierto. Terra Latinoamericana 2009;27:115–21. https://www.scielo.org.mx/pdf/tl/v27n2/v27n2a4.pdf

[25] Friendly M, Fox J. Candisc: Visualizing generalized canonical discriminant and canonical correlation analysis. R (≥ 350) Version 08-6 2021. https://cran.r-project.org/web/packages/candisc/index.html

[26] R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing. GNU Project 2021. https://www.r-project.org/about.html

[27] Howeler R. Desordenes nutricionales. 1st ed. Santiago de Cali, Colombia: Centro Nacional de Agricultura Tropical - CIAT; 1983.

[28] Norton B. Differences between species in forage quality. In: Hacker J, editor. Nutritional limits to animal production from pastures. 1st ed., United Kingdom : Commonwealth Agric. Bureaue, Farnham Royal, UK; 1981, p. 89–110.

[29] Canham CD, Berkowitz AR, Kelly VR, Lovett GM, Ollinger SV, Schnurr J. Biomass allocation and multiple resource limitation in tree seedlings. Canadian Journal of Forest Research 1996;26:1521–30. https://doi.org/10.1139/x26-171

[30] Chapin FS. The Mineral Nutrition of Wild Plants. Annu Rev Ecol Syst 1980;11:233–60. https://doi.org/10.1146/annurev.es.11.110180.001313

[31] Huante P, Rincon E, Acosta I. Nutrient Availability and growth Rate of 34 Woody Species from a Tropical Deciduous Forest in Mexico. Funct Ecol 1995;9:849. https://doi.org/10.2307/2389982