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Cover Photograph: Adult *Nassella tenuissima* clumps among American basketflower fields in the remnant shortgrass prairie of The Department of Natural Resources Management at the Texas Tech University. Photograph taken by Dr. Juan G. García-Cancel.

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Spatial Arrangement and Potential Detrimental Effects of *Nassella tenuissima* on an Urban Remnant Shortgrass Prairie in West Texas

Juan G. García-Cancel[1,2*] and Robert D. Cox[2]

Abstract: We investigated the spatial distribution of *Nassella tenuissima*, an invasive grass, in an urban native remnant shortgrass prairie, as well as its effects on a native grass species, *Bouteloua gracilis,* in a glasshouse setting. We first mapped populations in a native prairie remnant to determine spatial distributions of adult *N. tenuissima* clumps, and detected a high level of aggregation in the field. We then set up an additive competition experiment to determine at which density *N. tenuissima* influences growth and nitrogen allocation of native grass seedlings. Higher *N. tenuissima* density had a detrimental effect on growth for *B. gracilis* seedlings, while *B. gracilis* had higher biomass and nitrogen accumulation with no *N. tenuissima* present. Our results suggest that the effects of invasive grasses can start with very low numbers in early life stages in the field. Management and control of these should be done sooner rather than later when density increases with more propagule rain. In urban settings, *N. tenuissima* may rapidly invade native prairie remnants, and could significantly alter biodiversity and ecosystem attributes.

Introduction

Terrestrial ecosystems around the planet are experiencing shifts in species assemblages due to human activity, including both introductions of non-native species (DiTomaso et al. 2017, Kreyling et al. 2011, Lockwood et al. 2007) and anthropogenic climate change (Vitousek et al. 1997). Species that are transported by humans and are able to survive and reproduce in their new systems could potentially become invasive if their environmental impacts are on a large scale and affect human economic or cultural activities (Lockwood et al. 2008). Plants in particular can be inconspicuous when initially introduced and only once they have increased does their effect on the ecosystem become noticeable (Crooks 2005), and perhaps nearly irreversible (Evans et al., 2017).

Invasive species can affect native species through multiple pathways; including through soil nutrient dynamics, competition, shading effects, or by direct competition for soil resources due to their extensive root system (García-Cancel and Thaxton 2018, Ibarra-Flores et al. 1999, Parkinson et al. 2013, Rojas-Sandoval and Meléndez-Ackerman 2012). Some invasive plants can alter the dynamics in ecosystems by exerting indirect competition pressures with native plants by deterring herbivory on their tissues, forcing herbivores to eat more palatable plants (Mapaura et al. 2020).

The spatial arrangement of plants in a landscape can also accentuate the effects they might have on other local plants by monopolizing resources (Archer et al. 2017), or by providing valuable aid at key life stages (García-Cancel and Thaxton 2018, Padilla and Pugnaire 2006). Therefore, spatial arrangement of plant populations can show past his-

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torical trends in propagule arrival and spread (Seabloom et al. 2006). Even geographically restricted native plants could be released from their constraints and become invasive in introduced regions if the biological barriers such as mountains, oceans or deserts are bypassed (Seabloom et al. 2006, Vilà and D'Antonio 1998). The same can happen when disturbance regimes have been altered and have weakened the native species pool, making them susceptible to invasion (D'Antonio and Vitousek 1992, Suding et al. 2004), including in grasslands (Seabloom et al. 2013).

Dispersal of non-native plants from urban centers is a common occurrence (Beaury et al. 2021, Veldman and Putz 2010) that has accelerated the rate of biodiversity loss and breakdown of ecosystem services globally (Suding et al. 2004). Some have argued that urban green spaces can act as ecosystem service providers in lieu of native robust ecosystems by providing services *e.g.* nectar providers (Yessoufou 2023); or sources of adaptability to changed local soil conditions (Honfi et al. 2023). Others have found that urban green places can act as reservoirs and sources of ornamental, potentially invasive plant species capable of spreading into nearby native areas (Knapp et al. 2012, Reichard and White 2001, Shah et al. 2025).

Nassella tenuissima (Trin.) Barkworth (Mexican feathergrass) is an invasive grass in the Southern High Plains of the continental United States, but native to the arid Trans Pecos region of Texas, northern Mexico and southeastern New Mexico, with some populations in southern South America (Humphries and Florentine 2021, Jacobs et al. 1998). It has been introduced in several locations as an ornamental plant (Fig. 1), and it has been observed to remain in the seedbank up to 7 years or longer after removal of adult plants (Moran et al. 2018). In environments with more water availability, such as in urban land-

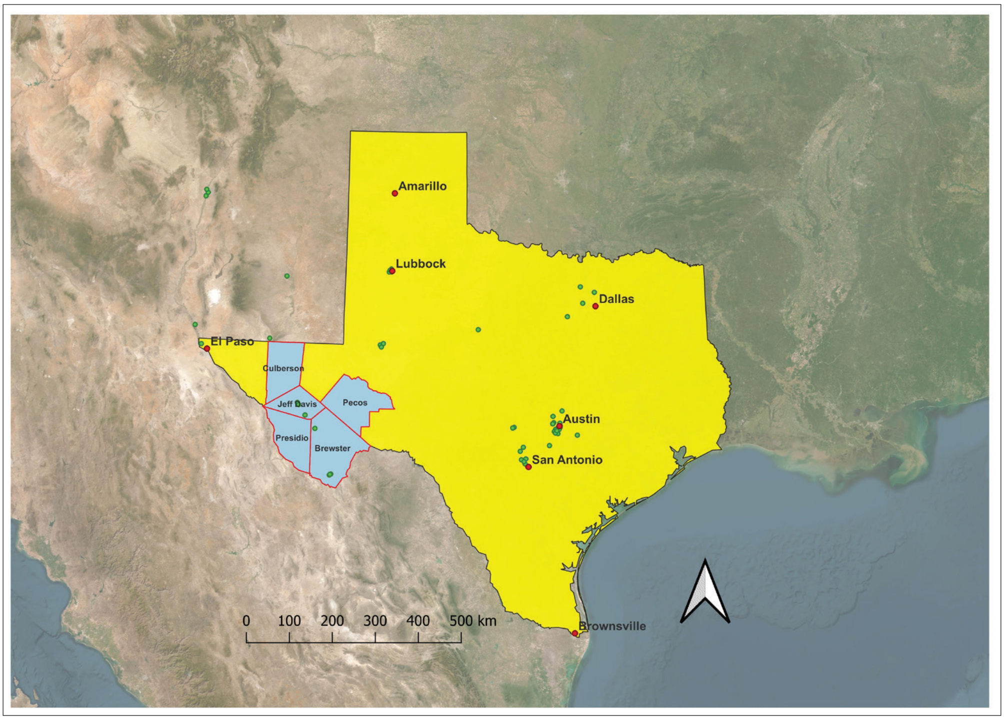


Figure 1. Native locations of *N. tenuissima* in TX (blue counties) and known locations (green circles) of *N. tenuissima* in the state of Texas as of April 21, 2021. (QGIS geographic information system).

scaping, this grass can spread rapidly to nearby ecosystems due to its high seed output (Humphries and Florentine 2021, Moran et al. 2018, Russell and Rector 2016).

Bouteloua gracilis (Kunth) Lag. ex Griffiths (Blue grama), (syn. *Chondrosum gracile*) is a C_4 warm-season perennial caespitose grass located mainly in the North American shortgrass prairies (Anderson 2003, Wynia 2007). The species has a wide range in the North American Central Plains, from south Canadian prairies (Wilson and Pärtel 2003) to northern Mexico (Anderson 2003). The broader genus has a Pan-American distribution, with 57 described species (Siquieros-Delgado 2007).

B. gracilis is a fast-reproducing grass, able to reproduce asexually by stolons and sexually by outcrossing wind-pollination and wind dispersed seeds (Anderson 2003). Its foliage has a high nutrient content which is favored by livestock (Melgoza-Castillo et al. 2014), and it is readily used in restoration efforts due to easy germination rates (Bakker et al. 2003). *B. gracilis* has the ability to suppress some invasive grass species with its high germination rates occupying available space (Wilson and Pärtel 2003). On that regard it has also been documented to have a strong ability to extract soil moisture by the profuse root system of adult plants (Dormaar et al. 1994), though in some studies *B. gracilis* did not rapidly spread in highly disturbed sites with the presence of other competitive perennials (Samuel and Hart 1994).

The early effects of *N. tenuissima* invasion in a remnant shortgrass prairie embedded in an urban matrix have not been studied. To study the spatial patterns that such an invasive might have, we carried out a field study to determine the presence and spatial patterns of *N. tenuissima* plants in the remnant rangeland in an urban matrix. We hypothesized that *N. tenuissima* clumps will be clustered instead of being randomly distributed and that their densities will be higher than randomly expected. We also conducted a greenhouse competition experiment with *N. tenuissima* and the native shortgrass prairie grass *Bouteloua gracilis*. We hypothesized that increasing density of *N. tenuissima* would impact biomass production and nitrogen tissue allocation in *B. gracilis* individuals.

Methods

Experimental design: Field study

We studied the spatial distribution of *N. tenuissima* in a 160-acre remnant shortgrass prairie (33° 36’9.36” N, -101° 54’ 2.52” W) managed by the Department of Natural Resources Management, Texas Tech University, in Lubbock, TX (Fig. 1). The presence of *N. tenuissima* had been observed as early as 2014. We established 25 parallel transects, measuring around 700 m long and 3 m wide, 30 m apart. A positive sighing of a Mexican feathergrass clump would be recorded by a geotagged photograph along these transects during the days of May 15–16, 2019 and June 24–25, 2019. We then used Point Density Analysis as part of the Density Analysis toolbox from ArcGIS (Esri©) to produce Average Nearest Neighbor between grass clumps to determine if there was a clustering of the plants and a High/Low Clustering (Getis-Ord General G) to determine the likelihood that the cluster pattern could be the result of random chance (Getis and Ord 1992, Mitchell 2005).

Experimental design: Glasshouse

We carried out addition competition experiments in the TTU glasshouses in Lubbock, TX, USA (33° 35’ 3.066” N, 101° 53’ 13.1199” W) with seedlings of *N. tenuissima* and *B. gracilis*. We used seeds collected from adult *N. tenuissima* from the remnant shortgrass prairie administered by the Department of Natural Resources Management, Texas Tech University, in the summer of 2021. Seeds were rinsed with a 10 % chlorine bleach solution to limit the occurrence of phytopathogenic fungi and bacteria and seeded for the experiment in Spring 2022. For the native component of this experiment, we chose *B. gracilis* due to its widespread distribution and importance for shortgrass prairie ecosystems in North America (Melgoza-Castillo et al. 2014), in addition to its easy availability from commercial vendors. To that end, *B. gracilis* seeds for this study were purchased from Bamert Seed Company, Muleshoe, TX.

We designed an experimental additive design, with the target species being *B. gracilis* and the subsequent addition of *N. tenuissima* in increasing numbers. Seeds from both species were germinated in sterile greenhouse soil media (BM6 All-Purpose Optimal Porosity Mix, Incubated pH = 5.4–6.2 Berger ©) in Spring 2022 in controlled greenhouse conditions at 25° C. Once germinated, seedlings were randomly assigned into five replicates of six treatments ranging from 0–5 *N. tenuissima* per pot. Each pot was a 2-gallon (7.5 L) nursery pot (19D x 24.63W x 20.63H cm) and had a single *B. gracilis* individual and 0–5 individuals of *N. tenuissima*.

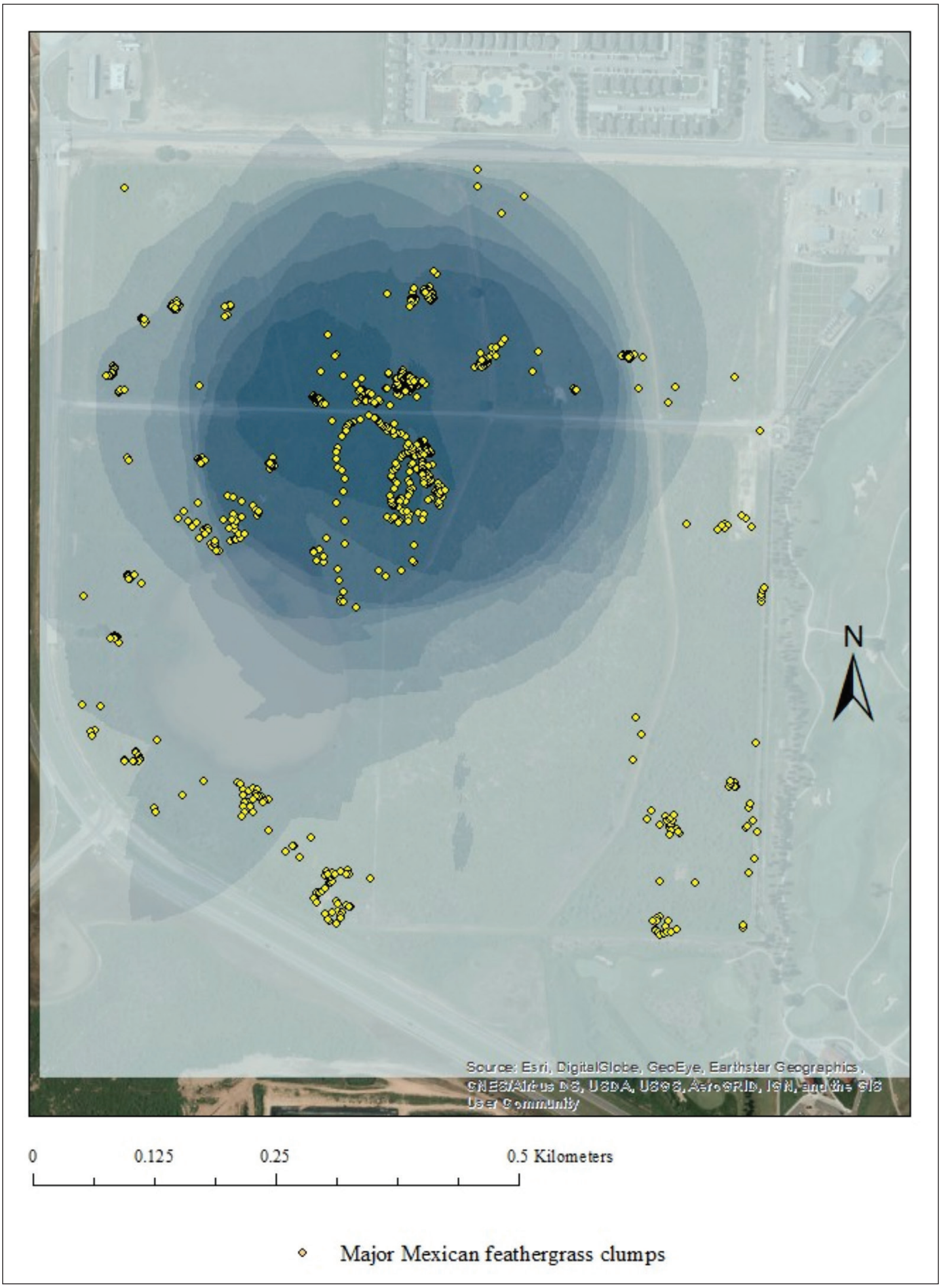
All pots were watered to saturation (on average 511.6 mL per 5 seconds) once a week and allowed to dry between waterings. Gibson et al. (1999) warned about the use of additive designs in greenhouse conditions, as researchers focus on harvest end data and not other factors that might be at play in the plant dynamics; such as the interactions of shoot and roots and their relation to plant species performance. We mitigated this by collecting data on available soil moisture using gravimetric soil moisture measurements, and biomass growth output at the time of harvest, with distinction for above and below ground organs and nutrient allocation in selected experiments. Biomass samples were weighed after harvest before being oven dried, and weighed a second time to estimate dry weights of the plant matter. All biomass measurements were analyzed using one-way ANOVA using the program Infostat© (DiRienzo et al. 2008). Fixed factors were species identity and invasive plant density as categorical data, while the dependent variables were wet and dry biomass production and above and below ground maximum length of the native seedlings. Biomass was weighed with a Mettler Toledo AL104 Balance and a standard measuring tape was used for measuring maximum length above ground as well below ground.

After harvest, plant matter was oven dried at 55.5 °C (~140 °F) for a period of 3 weeks and ground to 2 mm mesh size using a Wiley Mill for larger samples and smaller (< 0.5 mm) mesh size for smaller samples. For the tissue allocation of nitrogen under the treatments, we selected plants from four treatments, these being Treatment #0, #1, #3, and #5 to determine if increasing density of invasive grass also affected nitrogen deposition in above and below ground tissues. If ground samples were too large, they were further processed in the laboratory by freezing with liquid nitrogen and grinding with mortar and pestle before being rolled in tin foil and analyzed in an elemental analyzer (Costech-4010; Costech Analytical, Valencia, CA, USA). Spectral graphs from the combusted samples were produced, as well as data from the available percent nitrogen found in the analyzed samples. These data were analyzed by one-way ANOVA using the program Infostat© (Di Rienzo et al. 2011). The fixed factor was invasive plant density, while the dependent variables were biomass production of target native seedlings and nitrogen percentages in tissue samples. Ad hoc differences were analyzed using Tukey test.

Results

Field study

We found that *N. tenuissima* occupies large tracts of the 160-acre remnant prairie (Fig. 2), with a nearest neighbor ratio of 0.16 clump/m^2 (z-score = -51.6811, p-value = 0.00). Expected mean distance was 211.48 m, but observed mean distance was 34.49 m. The High/



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2. Point Density Map of known *N. tenuissima* clumps in the TTU Rangeland in June 2019.

Low Clustering (Geris-Ord General G) analysis showed a High-cluster spatial pattern (Observed General G = 0.02, *z*-score = 10.40, *p*-value < 0.01; Fig 2).

Greenhouse

Increased *N. tenuissima* plant density reduced biomass production for *B. gracilis* roots, but not for shoot biomass (Table 1). Soil water content was not statistically different between treatments ($\bar{x} = 1.33$, SE = 0.46, $F = 1.28$, $df = 5$, $p = 0.31$), and the presence of this invasive grass did not result in any difference in organ length. However, root biomass was significantly different between treatments (Table 1). Treatment #0 had significantly more root biomass (Fig. 3) compared to any other treatment. The presence of *N. tenuissima* did not affect *B. gracilis* shoot biomass (Table 1). Nitrogen content was statistically different between treatments for below ground samples, with highest nitrogen content in Treatment #0, but not for aboveground samples (Table 2).

Discussion

Spatial arrangement of the *N. tenuissima* clumps was highly clustered, implying that dispersal is limited, but the patches they colonize have a pronounced thatch formation. Mexican feathergrass thatch is problematic, being highly fibrous and resistant to degradation (Moretto et al. 2001), which could impose a limitation to native seed germination or emergence due the physical barrier imposed by the new thatch layer. Such barriers have been noted in other study systems (Evans et al. 2017). Future studies could well explore if the same barriers are present in the TTU Rangeland in Lubbock, TX.

N. tenuissima has been observed to easily expand once escaped from cultivation (Moran et al. 2018) and create dense patches (Fig. 2), which we now confirm has some effects in native plant growth and its nutritional potential of native plants for livestock fodder. It has been widely planted and exported in the ornamental industry due to its large range of drought tolerance and aesthetic value (Beaury et al. 2021). One of its impacts on native communities in California, New Zealand, and Australia include unpalatability for native herbivores, overgrazing more palatable grasses, and diminishing productivity of rangelands where present (Humphries and Florentine 2021, Moran et al. 2018, Russell and Rector 2016). Even in regions with precipitation as low as 300 mm

Table 1. ANOVA Biomass Analysis for the effects of *N. tenuissima* density on *B. gracilis* growth in the TTU Greenhouse. Values in bold are statistically significant. *p*-value = 0.05.

N	Organ System	Variable	*F*	*df*	*p*-value
30	Shoot	Length	1.12	5	0.3741
		Wet net biomass	0.97	5	0.4577
		Dry net biomass	1.18	5	0.3458
30	Root	Length	0.79	5	0.5679
		Wet net biomass	2.9	5	**0.0347**
		Dry net biomass	2.97	5	**0.0315**

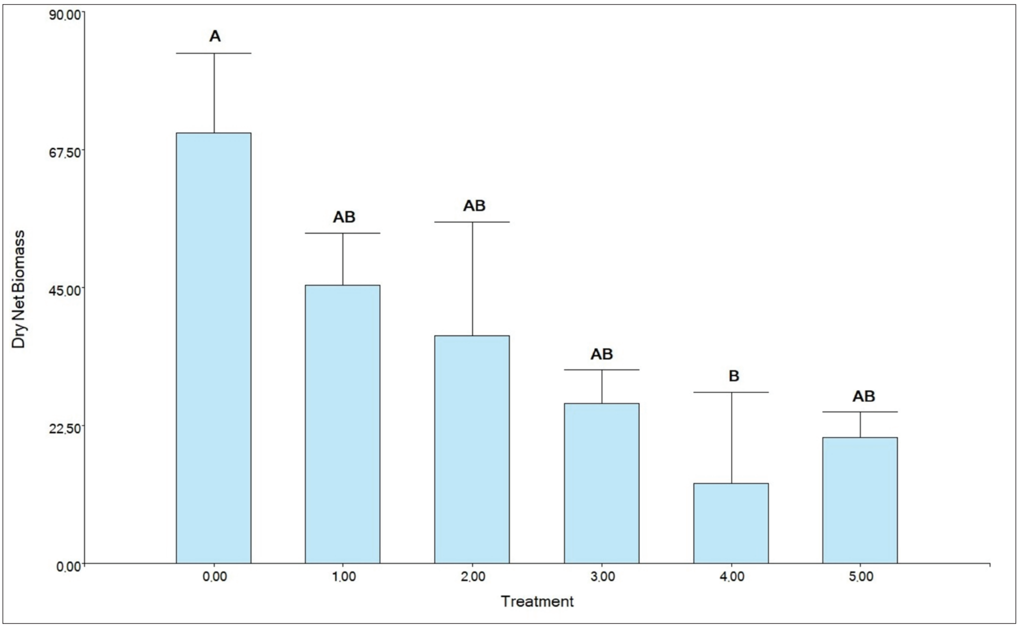


Figure 3. *Post hoc* Tukey Test for *B. gracilis* dry root biomass under increasing *N. tenuissima* density treatments for the summer 2022 growing season. *p*-value = 0.005.

Table 2. ANOVA analyses for the estimated organ nitrogen content in *B. gracilis* (nitrogen (g) per biomass) under increasing *N. tenuissima* density treatments for summer 2022 growing season. Values in bold are statistically significant. *p*-value = 0.05. Degrees of freedom = 3.

Organ System	*F*	*p*-value	Treatment	Means	*N*	Standard Error	Comparison	
			0	0.05	5	0.01	A	
Shoot	1.69	0.2085	1	0.04	5	0.01	A	
			3	0.04	5	0.01	A	
			5	0.02	5	0.01	A	
			0	0.20	5	0.02	A	
Root	9.65	**0.0007**	1	0.13	5	0.02	A	B
			3	0.05	5	0.02		B
			5	0.04	5	0.02		B

can grow *N. tenuissima* plants, making the central prairies of North America a suitable region for expansion.

In our experiment the presence of *N. tenuissima* did not cause remarkable differences in *B. gracilis* organ length, but it did reduce root biomass (Table 1). Treatment #0 had significantly more biomass for roots compared to the other treatments. This might have influenced the values for gravimetric water content, as the dense and profuse root systems of *B. gracilis* (Dormaar et al. 1994, Wynia 2007) might absorb water in comparable similar rates to the *N. tenuissima* roots. Nitrogen content in tissues for summer 2022 was higher for roots (Table 2) compared with shoots. However, some of the *B. gracilis* plants in Treatments #1 and #3 had already reached maturity and produced seeds, and may have begun withdrawing nutrients from the aboveground biomass.

Moretto et al. (2001) found that *N. tenuissima* and other unpalatable grasses in Argentina immobilize N in their litter. Nitrogen immobilization would impact nutrient dynamics in ecosystems where this grass has been introduced. For other *Nassella* species introduced in South Africa, the effects of these grasses have been noted to change herbivore behavior by forcing them to select more palatable vegetation, allowing the *Nassella* plants to expand with little competition (Mapaura et al. 2020). Not just wildlife is impacted, but also livestock as they cannot digest these grasses and when forced it can be harmful to the digestive tract of the herbivore (Campbell 1998, Mapaura et al. 2020).

Another serious issue that can arise from these grasses is the high deposition of leaflitter in yards and public spaces that could potentially create large fuel loads for fires (Bell et al. 2009, Fusco et al. 2019, Fusco et al. 2021). Other studies have mentioned the pivotal role fire has in grassland ecosystems (D’Antonio and Vitousek 1992, Neary et al. 1999, Williams and Baruch 2000), yet the alteration in disturbance regimes or secession of these altogether by land conversion can put human populations at risk (D’Antonio and Vitousek 1992, Fusco et al. 2021). Fire risk has risen in the past few decades (Setterfield et al. 2013, Fusco et al. 2019, Fusco et al. 2021). Range expansion of non-native grasses complicates this scenario (Di Tomasso et al. 2017) as some are present in urban settings (Fusco et al. 2021, García-Cancel 2023).

The introduction of *Nassella tenuissima* into new habitats via the ornamental market has allowed it to spread into nearby areas due primarily to high seed production (Humphries and Florentine 2021, Moran et al. 2018, Russell and Rector 2016). However, native areas invaded by this species might experience the detrimental effects of increased thatch, potential changes to fire cycles, and changes in nutrient cycling and native species biomass production. Urban landscapers should minimize the use of this grass due to the potential for harm to ecosystem services and interactions of native communities. More imminent to human safety is the potential of this grass to be a fire hazard, as it produces copious amount of leaf litter where present. This could provide an economic sink as mitigation of fire hazards and changing climatic patterns favor drying conditions in the study area.

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