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Article

Fire and dry grass: Effects of *Pennisetum villosum* on a California native, *Nassella pulchra*, in drought times

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SUMMARY

Invasive species pose a significant threat to many ecosystems, whether by outcompeting native species and disturbing food webs, or through increasing risks of natural disasters like flooding and wildfires. The ornamental grass species *Pennisetum villosum* R. Br. (also called *Cenchrus longisetus* M.C. Johnst.) was previously identified by the California Invasive Plant Council as being potentially invasive; this experiment was conducted to determine if *P. villosum* displays characteristics of an invasive species when grown in a California chaparral environment. This was done by growing it near a California native grass, *Nassella pulchra* (Hitchc.) Barkworth (also called *Stipa pulchra* Hitchc.), under both drought and non-drought conditions, and measuring the longest grass blades of each plant once a week. We found that in both conditions, the two species had similar germination rates, and that *P. villosum* grew significantly larger than *N. pulchra* for around 95 days. In control conditions, *P. villosum* then became reduced in size until it was significantly shorter than *N. pulchra*, while in drought conditions, there was no significant difference between the species. In this study, *P. villosum* did not negatively affect *Nassella pulchra*'s growth but may cause a fire hazard.

INTRODUCTION

Invasive species are one of humans' most significant environmental consequences (1). As we have covered the globe, we have brought our fellow life-forms with us, from houseplants to livestock. However, those other organisms often do not interact with new environments the same way they interact with their native habitats; some do not survive, while others are able to rapidly reproduce and take over their new homes. Species that exist in environments where they are not native are known as non-native species. Non-native species are not often harmful; in fact, they can even have benefits, such as providing food sources for humans or local species (1). However, when some non-native species cause harm to their new homes—whether by outcompeting local species, transmitting disease, overburdening the ecosystem, or other effects—they are classified as invasive species. Invasive plants can have severe repercussions, as the plants that they replace are often the foundation of an entire ecosystem or food web. Effects of invasive plants include taking over crops and pastures, causing economic damage to farms; outcompeting native plants, leading to possible extinction; and creating fuel for wildfires by increasing biomass and/or clogging waterways (2-4).

Intensifying wildfires have been a particularly devastating effect of climate change in recent years, and invasive plants are likely to have contributed to them (4-6). In California, five of the six largest wildfires in state history occurred in 2020, and over the year, more than 10.3 million acres of land were burned, costing an estimated $10 billion in damage (7). In addition to economic impacts, wildfires also produce smoke, which can have significant health impacts for humans, including (but not limited to) decreased lung function, increased susceptibility to respiratory and heart disease, and impaired neurodevelopment in children (6). Invasive grasses can play an important role in increasing wildfires wherever they are present, especially in creating what is called a grass-fire cycle, in which invasive grasses produce more biomass than native grasses, creating fuel for wildfires to burn longer and spread farther (8). The wildfires in turn clear out trees and other vegetation, allowing the grass to spread further (8).

Invasive grasses have replaced native species in over 9.2 million hectares of California grasslands (9). Therefore, it is important that we identify grasses that threaten to outcompete native plants, blanket entire landscapes, and offer fuel to wildfires. One of the most straightforward measures of determining whether a species is invasive or not is if it starves other species nearby in gathering resources, such as soil nutrients, sunlight, or water. In this experiment, we consulted the California Invasive Plant Council's (IPC's) inventory of invasive plant species and identified a common ornamental grass, *Pennisetum villosum* (feathertop grass) that is not yet invasive in California but has a high risk of becoming so. *P. villosum* is closely related to two other species already found to be invasive in California, *Pennisetum clandestinum* and *Pennisetum setaceum*. This experiment aimed to determine whether the growth of *P. villosum* caused reduced growth in a species of grass native to California, *Nassella pulchra*, when planted in close proximity, in both drought and non-drought conditions. *N. pulchra* was chosen because it is widely found in California and is a similar grass type to *P. villosum*. We found that *P. villosum* and *N. pulchra* seeds sprouted in similar numbers, and that *P. villosum* did not negatively affect *Nassella pulchra*'s growth. However, *P. villosum* could potentially cause a fire hazard.

RESULTS

To compare the growth rates of *P. villosum* and *N. pulchra*, we grew these two species in the same soil over 247 days. We set up our experiment in two containerized plots. Each had four alternating rows of *N. pulchra* and *P. villosum*, with four plants in each row (**Figure 1**). The implemented experiment setup in one of the plots was slightly different due to an error in planting, where the rows of *P. villosum* were sown next to each other rather than one row apart. The longest grass blade of each plant was measured every seven days, from the base of the plant to the end of the living portion of the blade. For example, although a grass blade may have longer than 10 cm, if the tips of it dried out and were not conducting photosynthesis, it would have been measured as less than 10 cm (**Figure 2**).

To learn whether *N. pulchra* and *P. villosum*'s relative growth rates would differ in drought conditions, we also compared the average longest grass blades of each species when available water was reduced by 50%. Plants were watered using an oscillating sprinkler, so available water was reduced by running the sprinkler for half as long in the drought box as in the non-drought box (**Figure 3**).

On average, *N. pulchra* in non-drought conditions grew to about 41 cm over 80 days, then remained at that length until Day 180 of the experiment. The average longest blade length then increased until the end of the experiment. The average length of *P. villosum* in non-drought conditions increased to about 58 cm within the first 65 days of the experiment, but from Days 90 - 150, it decreased to roughly 27 cm, where it remained for the rest of the experiment (**Figures 4, 5**). In non-drought conditions, the average longest blades of *P. villosum* were significantly longer than those of *N. pulchra* from Days 30 - 114, but *N. pulchra* was significantly larger than *P. villosum* from Days 136 - 247 (**Figure 6**).

In drought conditions, *N. pulchra* displayed a similar pattern to in non-drought conditions, but with lower average lengths: in the first 50 days it grew to 24 cm, then generally remained there, though the average longest blade started to increase around Day 180. *P. villosum* also showed similar patterns in drought conditions as in non-drought conditions: it grew on average to 37 cm within 65 days, but decreased from days 90 - 150 to around 18 cm (**Figures 4, 5**). In drought conditions, *P. villosum* was significantly longer than *N. pulchra* between Days 30 - 93, but during the remainder of the experiment, neither species was significantly shorter than the other (**Figure 7**). This suggests that *P. villosum* has a greater initial growth rate than *N. pulchra*, but that it tends to become reduced in size and is not on average larger than *N. pulchra*.

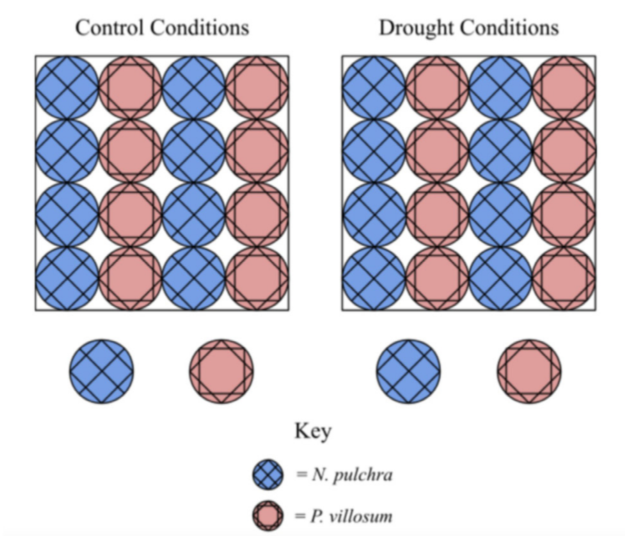

Figure 1. Diagram of initial experiment setup. *P. villosum* (red circles) and *N. pulchra* (blue circles) were grown over the course of 247 days in two different planter beds, one simulating normal amounts of precipitation while the other simulated drought conditions, with precipitation reduced by 50%. Within each box, there were n = 8 plants of each species (except for *N. pulchra* in the drought box, as one of the plants did not sprout; this plant was not included in data analysis). We chose to alternate rows of each species because we were uncertain whether proximity to other species, as opposed to being near plants the same species, would affect growth; this arrangement allowed each plant to be near both.

Figure 2. Measurement of a blade of *P. villosum*. This blade of grass would only be measured as 6.4 cm.

Figure 3. Oscillating sprinkler watering non-drought and drought beds, day 1. The drought bed received 50% less water than the control/non-drought bed (see Table 1 for exact amounts). The sprinkler put out roughly 0.2 cm of water per minute, so the amount of water each bed received was measured by the length of time the sprinkler was run.

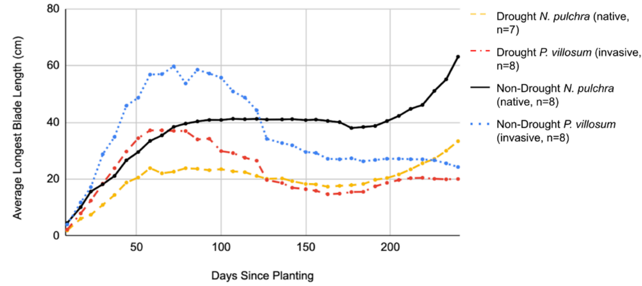

Figure 4. Graph showing average longest grass blades from each category, over 247 days. The red dashed-and-dotted line represents the average of the eight *P. villosum* plants in drought conditions, the dashed yellow line represents the average of the seven *N. pulchra* plants in drought conditions, the dotted blue line represents the average of the eight *P. villosum* in control/non-drought conditions, and the solid black line represents the average of the 8 *N. pulchra* in non-drought conditions. Within each species, the plants in drought conditions had shorter blades on average when compared to their counterparts which received normal amounts of water.

Additionally, since *N. pulchra* was significantly larger than *P. villosum* in non-drought conditions only, it may not grow as well in drought conditions.

Shortly before Day 200, the *N. pulchra* plants in both boxes developed cylindrical stems, as opposed to the flat blades of grass, with inflorescences at the ends, and often with shorter grass blades branching from them. These stems caused some difficulty in determining the lengths of the longest grass blades, as the blades branching off from the stem were higher than grass blades that started at the plant's base. We chose to measure from the base of the stems, which caused the average lengths of the blades of *N. pulchra* in both conditions to increase (**Figures 4, 5**).

Three to six seeds were sown together to ensure germination for each "plant"; when they first sprouted, the number of individual sprouts were counted, until each "plant" had so many stems that it became impractical to count them. A Student's t-test was then performed on this data, comparing the number of *N. pulchra* and *P. villosum* in each condition for each week. Comparison of the plants in non-drought conditions returned p = 0.3258, 0.0077, and 0.1007 for the three weeks that data was recorded; comparison of plants in drought conditions returned p = 0.8383, 0.6687, and 0.6975. Since none of the tests returned a p-value less than 0.05, we determined that the difference between species in number of sprouts was not statistically significant, and thus neither species' seeds appeared to have greater viability than the other's.

Starting on Day 65, the widths of random grass blades were also measured; however, the differences in average blade width across species and water availability conditions were not found to be statistically significant.

DISCUSSION

P. villosum was selected for study from the California Invasive Plant Council's (IPC) list of potentially invasive species, because two of its close relatives, *Pennisetum setaceum* and *Pennisetum clandestinum*, have been found to be invasive in California; *P. clandestinum* is classified as a noxious weed by the California Department of Food and Agriculture, and *P. setaceum* has been found to be well-adapted to fire, allowing it to survive and grow back more densely after wildfires occur, and also creating more fuel for future fires (10-12).

We performed a two-tailed, equal variance Student's t-test on the data for each week, comparing the two species in each condition. For example, one test compared the average longest blade of *N. pulchra* in the drought box to the average longest blade of *P. villosum* in the drought box, nine days after planting seeds. An F-test that also compared the species in each condition showed that in most weeks they had equal variance; thus, we performed an equal variance t-test. If the t-test returned a p-value less than 0.05, the difference in average longest blade was considered statistically significant. Thus, we determined that the non-drought plants' average longest blades were significantly different between Days 30 - 114 and Days 136 - 240 (**Figure 6**). The average longest blades of plants in drought conditions were significantly different on Day 30 and Days 51 - 93 (**Figure 7**).

In the non-drought conditions, *P. villosum* had longer average blades than *N. pulchra* from Days 30 - 114. However, *P. villosum*'s average length began to decrease around Day 80 of the experiment, until it eventually became on average shorter than *N. pulchra*, starting on Day 136. This was due to the tips of *P. villosum* grass blades dying off (quantitatively visible in **Figure 2**) since the dry sections of a grass blade were not measured. In drought conditions, *P. villosum* also tended to be longer on average than *N. pulchra* from Days 30 - 93 of the experiment, but the blades became shorter until there was no statistically significant difference between *P.*

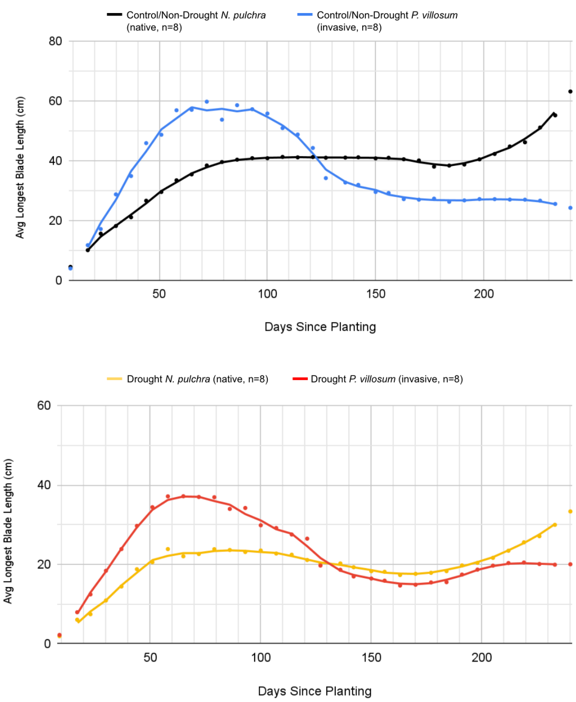

Figure 5. Moving averages over a period of three weeks of mean longest blade length in non-drought (top) and drought (bottom) conditions.

villosum and *N. pulchra* in drought conditions.

P. villosum being larger than *N. pulchra* within the first few months of the experiment suggests that it has a faster initial growth rate than *N. pulchra*. However, since *P. villosum*'s average blade length decreases in both conditions, causing the difference becomes insignificant around Day 114, this initial growth rate is likely not sustained throughout the plant's lifetime, and as such *P. villosum*'s growth during this experiment did not result in its overcrowding *N. pulchra*. This corroborates with prior research on other invasive plants in California, which found that invasive plants were not more competitive than native plants; however, this research also found that invasive plants were less likely to be affected by grazing, leading to their dominance in grazed areas. Thus, as farms and ranches spread across California's landscapes, native plants were still gradually replaced with non-native species (12).

In non-drought conditions, there was a period in which *N. pulchra* was significantly larger than *P. villosum*. This suggests that *N. pulchra*'s growth is more limited by drought conditions than *P. villosum*'s since this did not occur in drought conditions. However, this does not necessarily mean that *P. villosum* will outcompete *N. pulchra* in drought conditions, as *P. villosum* was not significantly larger than *N. pulchra* in drought conditions for most of the experiment.

During the experiment, there were several outside factors that may have impacted the development of the two species, or which prompted minor changes to the experimental design.

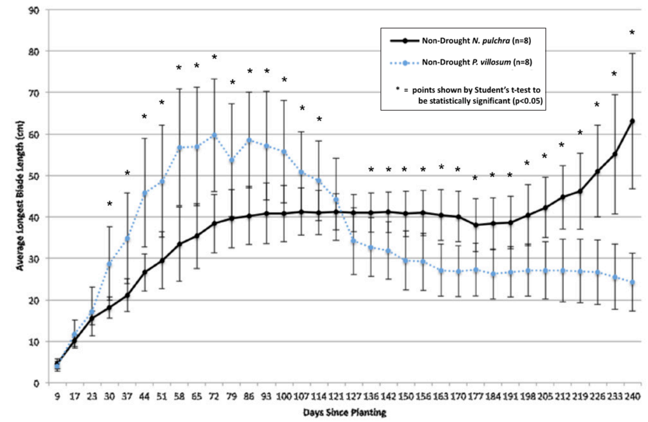

Figure 6. Average longest grass blades of *P. villosum* (blue line) and *N. pulchra* (black line) in non-drought (control) conditions. Error bars show standard deviation for each point. Asterisks show data points where the difference in blade length between the two species was determined to be statistically significant using Student's t-test. At these points, a t-test returned p-values less than 0.05.

First, there were times when the plants would receive water outside of the experiment schedule, such as in rainy weather; this was accounted for by covering the plants with a cage covered in transparent plastic to prevent precipitation from falling on plants, and by installing a rain meter to measure any precipitation that may have been blown under the cover. Extraneous watering is not likely to have caused a significant change in experiment results, as any additional watering was measured and accounted for by reducing subsequent water amounts. Additionally, the amount of water given to the plants was based off an average, so it is possible that under natural conditions, the grasses would get more rainfall than was simulated in the experiment.

Weeds that sprouted in the experiment boxes were removed weekly to prevent them from competing with the experiment plants for resources. Some that sprouted near the base of experiment grasses could not be entirely removed in case their roots were associated with the experiment grasses; these were trimmed to the base to prevent photosynthesis, so that the roots would die off. However, this removal of competitors likely does not accurately reflect conditions in natural California ecosystems. To increase accuracy, it may be beneficial in future experiments to research the composition of species in California chaparral environments and plant a greater variety of species to determine whether *P. villosum* may affect other species of plants.

Another external factor was air quality. Starting on day 10, there was heavy pollution in the atmosphere due to smoke from nearby SCU Lightning Complex wildfires (**Figure 8**). Smoke from wildfires could have influenced the growth of both species, though previous studies are inconclusive in terms of effects of wildfire smoke on ecosystems. While particulate matter blocks plants from sunlight and gas exchange, it also diffuses light in a manner which increases productivity (13).

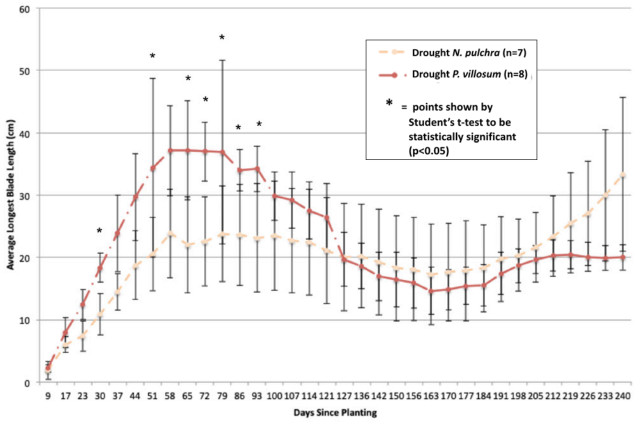

Figure 7. Average longest grass blades of *P. villosum* (red line) and *N. pulchra* (yellow line) in drought conditions. Error bars show standard deviation. Asterisks show data points where the difference in blade length between the two species was found to be statistically significant using Student's t-test. At these points, a t-test returned *p*-values less than 0.05.

Additionally, ash contains toxic levels of certain compounds, as well as essential nutrients (14). Thus, the impact of poor air quality on the experiment cannot be determined without further study. Air quality fluctuated over the months following Day 10 as subsequent wildfires caused increases in AQI (air quality index). Records were kept of daily air quality, based on measurements made by the Bay Area Air Quality Monitoring District's Redwood City monitor (AirNow.gov). In future experiments, this factor could be eliminated by performing the experiment indoors, such as in a greenhouse, or in a similar climate-controlled space. It may also be an interesting future study to analyze the effect of AQI on plant growth.

There were also several instances of insects preying on the grasses, most noticeably an aphid infestation that began on an invasive plant in the drought box around Day 86. This infestation was treated first by manually removing individuals weekly, then by using an insecticidal soap once a week. This was effective, as within a week of initial treatment, few or no aphids were observed on any plants. The aphid infestation also could have influenced the experiment if either species was particularly sensitive to damage by insects, or if the aphids increased the risk of infection from environmental factors. This factor could also be eliminated by performing the experiment indoors or in other similar climate-controlled space.

These external factors would likely need to be more closely controlled in future experiments, as it is possible that they affected the growth of either species of grass, causing inaccurate results. Furthermore, the control individuals were not measured past Day 19 of the experiment, as the non-drought control group failed to germinate, and the drought control group's container was knocked over on Day 19, leading to loss of sprouts.

In this experiment, we considered the flowering stalks of *N. pulchra* to be the same as grass blades when measuring plant size. However, measuring stalks and blades separately in future experiments may increase the accuracy of the results, as the two structures have different properties, and since *P. villosum* does not have analogous flower stalks, this could possibly lead to a poor comparison of the species.

Future studies could also improve this experiment by addressing other measures of viability and growth rate. For example, analyzing the number and viability of seeds of each species over multiple generations would likely be an equally, if not more, helpful measure of invasiveness than average longest blade length. This could be tested by collecting and counting the seeds from each category of grass in this experiment, then planting a random sample of seeds in the same conditions and counting the number of sprouts and measuring their growth rates. If *P. villosum* were found to produce more seeds with the same viability as *N. pulchra* over a certain period, then it may be more likely to be invasive.

During this study, it was not determined whether *P. villosum* would contribute to wildfires or not. The nonliving sections at the ends of *P. villosum* grass blades could potentially be more flammable due to lower water content, but as they were not measured in this experiment, further research is required to prove this (15). Dry biomass may be another indicator of whether *P. villosum* contributes more to wildfires, but this was also not measured in the experiment due to lack of equipment. As mentioned previously, wildfires are an increasingly devastating threat not only to environments, but also to human lives and property. Thus, it is important that we find ways to prevent and limit their spread, such as by limiting the spread of invasive species that fuel fires to burn longer, hotter, and farther. One important way to prevent the introduction of invasive plants is to remove them from gardens. Currently, many highly invasive plants are still easily available for purchase in nurseries or online (16). A significant fraction (34-83%) of invasive plant species are found to be of horticultural origin, so by reducing the sale of invasive species, we can limit their impact on ecosystems (17). This reduction can be achieved by labelling plants in nurseries as invasive, as a 2001 study found this to be an effective method of spreading awareness of the issue (18).

MATERIALS AND METHODS

To determine the effect of *P. villosum* on *N. pulchra* without external interference, seeds were sown in two 2,304 in^2, 10.5-inch-deep planter beds, in landscaping soil ordered from Lyngsø Garden Materials. All seeds were ordered online; the *P. villosum* seeds were bought from Johnny's Selected Seeds, and the *N. pulchra* seeds were ordered from Larner Seeds. Each bed contained four rows of plants, each row alternating between *N. pulchra* and *P. villosum*, with four plants in each row (**Figure 1**). Three to six seeds were sown for each "plant" to ensure germination in each one. A few seeds from each species were also sown separately in individual flowerpots to serve as controls, or to show if either species grew more (or less) successfully in the absence of the other species. Twofoot-high cages made of PVC piping and chicken wire were placed over the top of each bed to prevent local wildlife from interfering with the experiment (**Figure 3**). During the rainy season, these cages were covered in clear plastic wrap to prevent rain from falling on the experiment, and thus better control the amount of water the plants received. In case any precipitation did occur, a rain meter was placed in one of the planter boxes to monitor the amount of precipitation, which could then be accounted for in future watering of the plants. Following an infestation of aphids, the plants were treated with an insecticidal soap (EndAll, made by Safer® Brand) containing 1.00% potassium salts of fatty acids, 0.900% clarified hydrophobic extract of neem oil, and 0.012% pyrethrin.

Watering

The beds were watered for five minutes each day until the seeds sprouted with an oscillating sprinkler with a rate of about 0.2 cm of water every minute. Then, the amount of water given to each box was adjusted to reflect conditions in *N. pulchra*'s natural environment, with the non-drought box receiving the average amount of water that would fall in a California chaparral environment, and the drought box being watered for only half as long (19). The grasses were watered once a week, and the amount of time that they would be watered was changed every four weeks to reflect seasonal changes that occur in the California chaparral environment (**Table 1**).

Growth measurements

The length of the longest grass blade of every plant was measured with a ruler once a week, to within one decimal place (1 mm). When the tips of grass blades dried out, only the green portion of the blade was measured, as that seemed to be the most accurate measurement of the living plant (**Figure 2**). Analysis set does not include plants that did not sprout.

Table 1. Average amount of rainfall in chaparral environments by month, in centimeters.

Months Since Germination	Water in Non-Drought Box per Month (cm)	Water in Drought Box per Month (cm)
1	5.1	2.5
2	2.5	1.3
3	1.3	0.6
4	0.3	0.1
5	1.3	0.6
6	2.5	1.3
7	5.8	2.9
8	13.7	6.9
9	14.0	7.0
10	15.2	7.6
11	11.4	5.7
12	11.4	5.7

Initially, the number of shoots in each cluster of plants was also recorded, until the grasses grew close enough together that it became difficult to distinguish between individual seedlings.

Starting at Day 65, leaf blade widths were also measured. Each week, four plants would be chosen from each box (one from each row; or two invasive plants and two native plants from each box). Three random leaves were then measured from each plant.

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