Friend or Foe: Investigating the Relationship between a Corn Crop and a Native Ragweed Population

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Summary

As the demand for food increases with the ever-growing world population, crop production and growing efficiency must also be sustainably increased. Many factors, including energy cost, land allocation, and water usage are known to have a great impact on crop production. In particular, competition from invasive and native species can greatly decrease the growth and viability of crops. In this work, we explored the relationship between a competitive plant species growth and crop yield. Thus, we measured the effects of competition from a non-crop population on field corn crop yield, comparing a test sample in which weeds were allowed to grow freely and a control sample in which weed growth was not permitted. Interestingly, after observing growth over several weeks, we found that the test sample containing the competitive species actually outperformed the control sample in terms of the corn population's height, ear yield, and mass of crop produced. This led us to conduct soil testing on both populations to quantify nutrient availability. We found that levels of calcium and/or magnesium were more abundant in the soil of our no-weed control sample compared to our test sample and could be inhibiting growth. From this experiment, we concluded that the relationship between crops and their neighboring species is more complex than competition alone, and depending on the circumstances, non-crop species can enhance growth.

Introduction

Predictions reveal that by the year 2050, the worldwide population, which is estimated to be nine billion, will call for double the amount of food that is currently produced (1). As a result, it is imperative that, among other things, crop production is optimized and expanded to meet the growing hunger problem (2). In particular, competition from other plant species can greatly decrease growth and viability of crops (3). Both invasive and native competitive species can adversely affect crop production (4). Invasive species, especially insects and weeds, can have a crippling effect on ecosystems and crop growth (5). It is estimated that from 1906 to 1991 invasive species caused $97 billion in damages to crops and wildlife in America alone (3). Today, American farmers have to deal with potential threats from over 5,000 different types of invasive species (3). Among the most disruptive are the olive fruit fly, cheatgrass, and the glassy-winged sharpshooter (5). Additionally, competition from native, non-crop species is known to have an adverse effect on crop growth (6). Currently, in North America, the most threatening weed populations for staple crops, such as corn, include giant ragweed, wild buckwheat, and waterhemp (7).

Many farmers already conduct tests on their land in order to determine how much fertilizer or manure to use, or what type of crop to plant that season (8). In addition, due to their potential negative impact on crop yield, competitive species and their relationship with crops have been well studied. In general, the impact of a competitive species cannot be considered independent of the crop. Instead, the effect of a given weed on crop yield depends on many factors, such as on the duration of interference, the life-history of the weed-crop system, and the time at which interaction takes place (9). Recent work has shown that weeds may be beneficial to agroecosystems in some contexts. Thus, understanding weed competition and identifying the weed species that have the greatest effect on crop growth is an important step in balancing the need for weed control with their potential use in biodiversity and sustainable growing methods (10, 11). Recent work has demonstrated that non-chemically based means for controlling weeds are becoming increasingly important as the repeated use of chemical intervention methods is steadily leading to the growth of treatment-resistant populations (12). To further understand the complex interactions between a crop and a competitive plant species, and to develop a model system for investigating non-chemically based intervention methods, we sought to directly address the impact of weed growth on a corn crop in a controlled and inexpensive manner.

In this experiment, we investigated the growth-reducing competition created by interspecies interactions amongst plants. The crop tested in this experiment, field corn, was chosen for its expansive growing range worldwide as well as its ability to be used for a variety of products that benefit humans (13). As a model for competitive non-crop species, a conveniently available native ragweed population was used. Two equal planters were set up; one as a control planter that was regularly maintained to eliminate weed growth, and a test planter in which a ragweed population, and soon various other species of weeds were allowed to grow freely. We expected that competition for nutrients would cause the sample surrounded by weeds to grow more slowly and less healthily than the control sample because invasive and non-crop plant species have been shown to cause ecological and economic damage, as well as significantly affect crop growth within a specific area (8, 14, 15). However, as the experiment progressed, contrary to our hypothesis, the crop surrounded by weeds grew stronger and healthier than the control crop. We attribute this outcome to the possibility that in this case, the weeds actually helped to balance nutrient levels in the soil. Ultimately, it is apparent that the interspecies interactions between field corn and common weeds are more complex than competition alone.

Results

The goal of this experiment was to determine how weeds and non-crop species affected crop production. Specifically, we expected that competition caused by the weeds would stunt the growth of a population of corn. To this aim, we examined growth and viability of two populations of corn during the development of the crop. The control sample, hereafter referred to as W-, contained no weeds growing above the surface of the soil. The test sample, hereafter referred to as W+, was left for weeds to grow amongst the crop.

To conduct the experiment, we divided a planter in half using cinderblocks, and filled each side with fresh topsoil. There was a natural ragweed population growing in the planter, and on the W+ side, the weed population was allowed to grow freely (Figure 1). In the W- sample plot, weed growth was monitored on a daily basis and once growth could be seen on the surface, the weed was removed using basic gardening tools. This was done to best ensure that the entire weed, including its roots, was removed. Eighteen individual crops were set up in each planter and observations were made each week for height, maturity of the crop, and the approximate abundance of weeds in the soil.

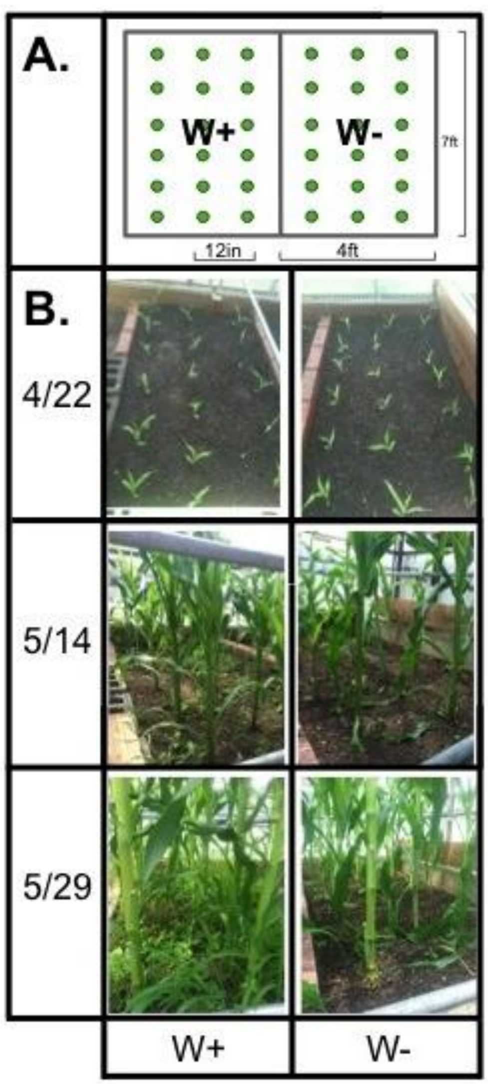

Figure 1. (A) Diagram (not to scale) of original planter and experimental setup. (B) Appearance of both the test (W+) and control (W-) samples at several critical time points from Table 1. Note: Images were not taken from the same height and angle, and are representative, but not quantitative, examples.

As seen in Figure 1 and Table 1, both samples grew relatively evenly at the beginning of the test. In fact, some characteristics of both samples, such as the average amount of husk produced and the coloration of the corn ears were not different throughout the duration of the experiment (data not shown). However, as the test continued, the W+ sample began to grow more quickly and appeared healthier than the W- sample. For example, as Table 1 indicates, in week four of the experiment, the W+ average height exceeded the W- average height by just 0.5 inches. Within two weeks this difference had reached four inches (Table 1). By the end of the growth period for each sample, the differences in health and growth are more clearly defined through crop production. Figures 2A and 2B demonstrate that the W+ sample produced 23 ears of corn total from 16/18 stalks, compared to the W- sample which produced 18 ears on 15/18 stalks. Also, the average ear length of the W+ sample was 8.69 inches, which is 12.1% longer than the average length of the W- sample (7.758 in).

Date	W+ Height (inches)	W- Height (inches)
15-Apr	2	2
23-Apr	3.5	3.5
30-Apr	4.4	4.5
14-May	18.5	18
22-May	21.334	20.667
29-May	41	38
20-Jun	15/18 touch ceiling	12/18 touch ceiling
27-Jun	All touch ceiling	All touch ceiling

Table 1. Average height of W+ and W- stalks over time.

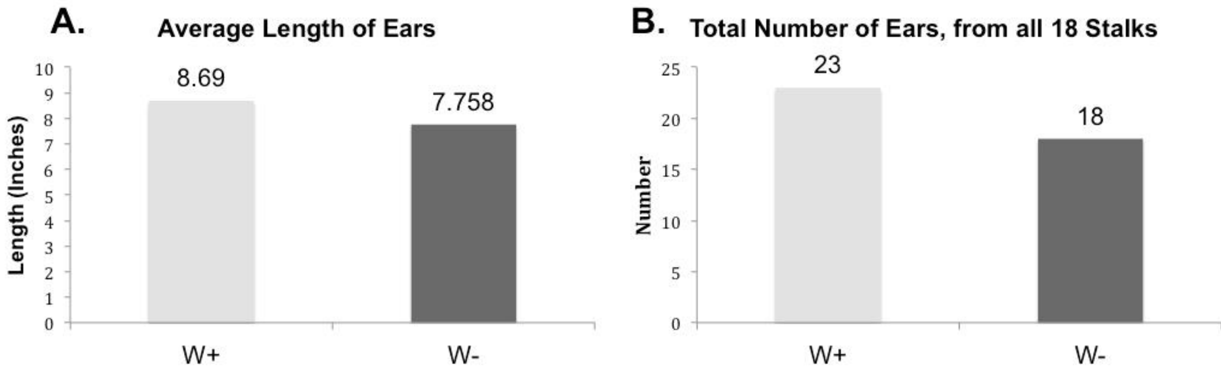

Figure 2. Average length (A) and total number (B) of ears produced by the W+ (light gray) and W- (dark gray) samples.

After observing that the W+ sample with the weeds was growing faster and healthier than the W- sample, we sought to find the source of this disparity. Plant species can potentially affect nutrient cycling in a variety of ways, from differences in uptake, loss, litter quality, and associations with microbes, to differences in effects on herbivory (16). One of the most common and easily testable factors affecting growth in a mixed population is nutrient availability. Corn is sensitive to nutrient levels in its environment and grows rapidly. Thus, optimal nutrition must be maintained to prevent growth deficiencies (15). Soil testing is a practical and inexpensive means of using reliable and empirical chemical analyses to assess important nutrient levels in soils (8, 17). Trace nutrients, for example, are nutrients that are critical to the health and viability of a plant, but can be harmful if present in excessive concentrations (18). Calcium and magnesium, though only secondary nutrients, are known to impact trace nutrient availability for corn plants (15). These nutrients are also easily detectable by simple soil tests (18). Thus, we sought to determine if a disparity in calcium or magnesium levels might have been the source of the observed growth difference.

To this end, we conducted a qualitative soil test to determine the relative levels of calcium or magnesium in the two populations. In this experiment, six soil samples were taken from each planter, mixed and examined in order to create an accurate average from each plot.

In this qualitative test, if calcium and/or magnesium are present in the sample, a color change from purple/blue to wine red is expected. Figure 3 represents the results from two technical replicates performed on the two samples. As seen in the figure, the wine red color indicates that, as expected, one or both of these nutrients was present in the W- soil at a level that is higher than the threshold of detection of the soil test (1.5meq/100g). In contrast, the purple/bluish solution seen in the W+ sample indicates that the calcium or magnesium levels in the W+ soil are below the threshold of detection and lower than calcium and magnesium levels in the W- soil. These results support our second hypothesis that the presence and possible imbalance of a nutrient was stunting growth of the W- test sample. Other nutrients and factors such as nitrogen, phosphorus, and sulfur could also contribute to this difference in growth (19-22). However, calcium and magnesium affect many features of corn growth, and were shown to be more abundant in the W- control sample (19). It is suggested that for the healthy growth of a corn crop, calcium levels should be between 601-1000 parts per million (ppm) and magnesium levels should be between 101-500 ppm (23). Because our examination of calcium was only binary and qualitative, a quantitative method such as atomic absorption spectroscopy (AAS) could be used to determine exactly how the levels of calcium and magnesium in both crops compare to these recommended levels (24).

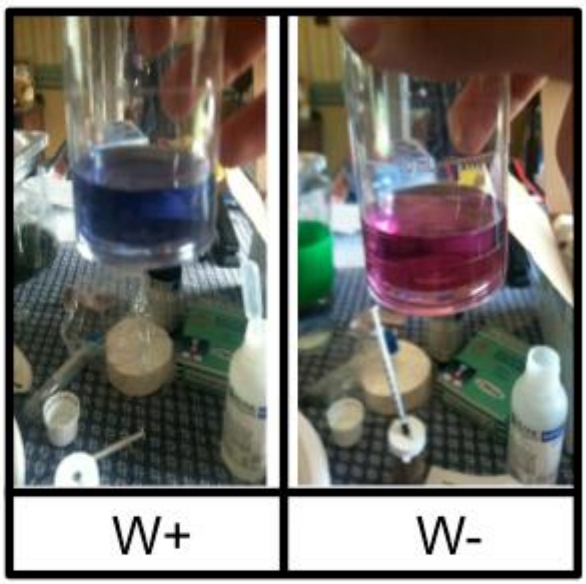

Figure 3: Qualitative appearance of the soil test (W+) and control (W-) samples following soil testing. Red color indicates the presence of calcium and/or magnesium. Six individual samples of soil were mixed and used for the soil test. These data are representative of two technical replicates performed.

These data imply that the presence of an invasive species or weeds amongst a crop may not always hinder growth and yield through competition. Instead, in this case, the presence of important or toxic nutrients and the balance of these nutrients appears to be most important. In this experiment, the non-crop species may have helped the growth and production of the crop in the W+ sample because the soil was rich in calcium and/or magnesium and the weeds helped to establish a balance of nutrients in the soil. It is likely that the W- crop had no buffer, and high levels of calcium and/or magnesium stunted growth.

Discussion

The goal of this experiment was to observe the effects of competition from model non-crop species on the growth of a corn crop. We originally expected samples in the W+ side to grow more slowly than the W- side due to competition from surrounding weeds that would leave the W+ crop malnourished. The experiment was performed by setting up two identical planters that received similar sunlight and water exposure each day and observing the growth and development of each crop over time for characteristics such as height, soil appearance, quantity of ears, size of ears, and thickness of the stalk. However, the data revealed that the W+ samples surrounded by weeds were outgrowing the W- samples. Because these data contradicted our hypothesis, we sought to investigate factors such as nutrient availability that can harm the growth of a corn crop. We tested the soil for the excess of two secondary nutrients, calcium and magnesium, which were indicated to be present in a larger quantity on the W- side than the W+ side. The results of this test indicate that, in this case, growth was not necessarily affected by direct competition from the weeds, but instead by other indirect relationships and interactions between the crop, soil, and competitive species. Our data suggests that these underlying factors must also be considered when evaluating the prospective success of a crop.

The effect of plant community structure on nutrient cycling is fundamental to our understanding of ecosystem function (20). Individual plant characteristics, such as lifespan, biomass allocation, and tissue chemical composition have been shown to have significant effects on ecosystem processes such as soil organic matter and nutrient dynamics (20). Specifically, nutrient dynamics refers to the way nutrients are used and reused over time and distance in a biological system (21). This process is relevant to this experiment because the organic matter of the soil was revealed to be rich in at least one of two secondary nutrients. The weeds in our W+ sample potentially influenced the nutrient dynamics of the soil, thereby helping to achieve a healthier balance in the soil for growing corn.

In this experiment, neither sample appeared to outgrow the other until about five weeks of growth. Soon, however, the W+ sample began to outgrow the W- sample. We hypothesize that this difference in growth rate can be attributed to the presence of inhibitory trace nutrients in the soil that didn’t contain weeds. Although each sample was planted in identical soil, we believe that the weed population in the W+ sample helped to balance out nutrient levels in the soil and enable faster growth. Additionally, it is possible that weed growth had not become sufficiently dense to neutralize the potential harmful effects of excess calcium and magnesium within the soil until week five of growth (Figure 1). This could explain the similar growth of the two crops until week five.

We tested for the presence of two nutrients, calcium and magnesium, in order to determine which facet of the interspecies interactions was influencing the growth of the corn crop on both the W+ and W- sides. Calcium and magnesium are secondary nutrients that help serve as regulators of many plant functions, and the levels of calcium and magnesium required for healthy crop growth varies with the condition of the soil (16). Though calcium and magnesium are less likely to be toxic on their own, they can impact the availability of trace nutrients for corn (15) such as nitrogen, phosphorus, potassium, and sulfur (22). These other nutrients could also have had a significant effect on the yield of each population in this experiment, and are also important for farmers to consider when testing their soil. However, the higher levels of calcium and/or magnesium do correlate with the growth and health defect seen in the W- population. As mentioned earlier, a quantitative method could be used to determine the levels of calcium and magnesium in both crops, and whether or not calcium and magnesium levels directly correlate with growth efficiency (24).

While it is conventionally believed that weeds stunt growth, their presence appears to have helped to enhance growth in this experiment. However, this surprising result can be explained if the nutrients in the soil were too rich, and the weeds helped buffer the W+ sample from an excessively nutrient-rich environment. To further examine how from non-crop species can affect crop yield, control of soil conditions would be critical. In future experiments, quantitative soil tests would be performed throughout the growth of the samples, and additional quantitative measurements of growth and total weed mass would be used to provide insight into the impact of non-crop species on crop growth patterns. Furthermore, crops could be grown solely in the presence of variable calcium and magnesium. By isolating calcium and magnesium as the test variables in this experiment, more conclusive evidence would be provided as to the influence of these nutrients alone on the growth and health of corn (18). Through the use of our existing model system with further controls, we could examine these complex interspecies interactions in greater depth. If it is observed that non-crop species do inhibit growth, further research could be conducted to examine the specific characteristics and weaknesses of competitive species in order to ultimately determine effective and low-impact intervention methods for combating non-crop species. In this way, our model could be used to conduct small-scale experiments to optimize large-scale, sustainable farming.

Interestingly, our model system could also be used to examine how the weed-crop interaction in this experiment compares to other interspecies interactions among crops. An effective technique that farmers and growers currently utilize to enhance growth of crops is companion planting, or the use of 'polycultures.' This system involves growing more than one crop within the same cultivation system (26). Research has shown that polycultures can be effective in weed suppression, combating insect damage, and better utilizing soil nutrients (26). A common polyculture technique is known as the 'three sisters method.' This method involves planting corn, beans, and squash all within close proximity to each other to help establish healthy nutrient relationships (27). For example, corn acts as a growing support for bean vines, while beans fix nitrogen into the soil to support the corn and squash, and squash helps to enrich the soil for the corn and beans (27). It is possible that similar interactions existed among the ragweed and corn in our experiment. Thus, using an expanded version of our current system, both competitive and polyculture interactions could be investigated to further examine these relationships.

This work demonstrates that the growth and development of a crop can be impacted by more than the presence of competition from native and invasive species. We suggest that the important factors to consider are not only the environment, the crop itself, and resident non-crop species, but also the ways in which these factors impact one another. Farmers around the world can help ensure a better harvest by doing preliminary research into the characteristics of a crop they would like to plant and comparing that to the known characteristics of the growing environment. Indeed, many farmers already conduct basic tests, such as soil sampling, on their land in order to determine planting plans for the upcoming season (8, 22). Our work reinforces the importance of soil testing, as conditions of the soil can have a measureable impact on the development of a crop, and soil analyses can provide information regarding the potential performance of a crop in a short amount of time. Finally, this study provides further evidence that the success of a crop is not just dependent on proper water, sunlight, and the control of weed growth but also on complex relationships within the growing environment. As globalization, alterations to the environment, and population growth further complicate crop production (13, 14). it is critical that the types of simple, and easily interpretable tests demonstrated here are used. In this way, farmers and growers around the world may seek out dynamic solutions to combat competitive species and optimize crop production to meet global food demands.

Materials and Methods

Planting

A single, floor-mounted planter approximately 8ft. x 7ft. in Northern Burlington County Regional High School greenhouse was used to conduct the experiment. The planter was divided into two sections using cinderblocks that were placed on the bottom, prior to the addition of topsoil. A ragweed population was growing in each side of the planter at the start of the experiment (Figure 1A). About 4’ of fresh, screened topsoil purchased from a local supplier was added to both sides of the planter and covered existing ragweed population. Eighteen field corn seeds (Carolina Biological Supply) from the same package were planted for each sample 8-10 inches apart and 3 inches into the soil. One hundred percent of seeds germinated.

Growth

Both samples were watered nearly every weekday for approximately 4 minutes each. Watering frequency and length were adjusted slightly during course of the experiment based on temperature and soil appearance. Weed growth was monitored in each sample throughout duration of experiment. Weed growth was uncontrolled in W+ sample. Once evidence of weeds reaching the surface was observed on W- sample, a trough was used to remove the weed including its roots to keep the environment controlled.

Data Collection

The height of each corn plant was measured from surface of planter to end of the stalk where leaves then branched off. This was done to provide a consistent basis for measurement, as the stalk is uniform in its appearance from beginning to end in each sample. Once samples began to reach the ceiling of the greenhouse, height became an impractical measurement and other characteristics were used. However, the change in ceiling height was consistent over both samples so the number of stalks that touched the ceiling in either sample was indicative of rate of growth in each respective population. Photos were taken weekly of both samples to help illustrate crop/weed growth and also taken at other points during the experiment to help illustrate significant changes or developments of the crop. Length of the ears of corn was calculated by measuring from the base where the ear attached to the stalk to the opposite end of the ear. To create a soil culture for each sample, six samples were taken from the four corners and center of each side of the planter. The six samples from each respective side were then mixed together to create a balanced soil culture representing conditions from both the W+ and W- samples. The soil test does not distinguish between calcium and magnesium in the soil (16). Two technical replicates of the soil test were conducted to confirm results. Hanna Instruments Calcium and Magnesium Soil Test Kit (HI 38080).

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