ABILITY FOR YELLOW STARTHISTLE TO COMPETE FOR SOIL RESOURCES AND PRODUCE SEEDHEADS

A Thesis

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Abstract

Yellow starthistle (*Centaurea solstitialis*) is a non-native plant of North American rangelands, which has been successful in establishing itself on areas previously occupied by native vegetation where it competes for soil and water resources. The objective of this study was to analyze the success yellow starthistle had in producing seedheads when competing for soil resources with native vegetation in a field study, and when resources were limited to simulate plant competition in a greenhouse study.

Soil depth, fertility, and moisture data were collected from macroplots which were classified into early seral (annual dominated vegetation), middle seral (mixed annual and perennial vegetation), and late seral (perennial dominated vegetation), for the field phase of the study. The greenhouse study examined germination and seedling growth of yellow starthistle at two levels of nitrogen, two levels of phosphorous, and four levels of soil moisture. In both studies, the production of seedheads was used as an indicator of the effects from plant competition.

The fieldwork phase of the study found no differences in seedhead production across seral stages. However, there were significant differences in soil depth across seral stages, with early seral plots having the deepest soil and late seral plot having shallowest soil. In addition, yellow starthistle plant densities were highest in early seral plots, and lowest in late seral plots. Therefore, intraspecific and interspecific competition probably had a negative effect on seedhead production on a given site, and soil depth is a major factor regarding the ability of yellow starthistle to invade a site.

In the greenhouse phase of the study there was an interaction in seedhead production among nitrogen, phosphorous, and percent soil moisture. However, with a reduction in one or all of these factors, there was a reduction in yellow starthistle seedhead production. Thus, indicating that if plant competition reduces soil resource availability for yellow starthistle, there would be a negative effect on seedhead production. This study also indicated that when high amounts of nitrogen were added to the soil, yellow starthistle seed germination was highly reduced.

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Finally, a special thank you to my family. My wife Shelley, and sons Matthew, Austin, Bryce, and Nathaniel, whose love, devotion, and caring helped make this possible.

Dedication

This thesis is dedicated to my wife Shelley, and my sons Matthew, Austin, Bryce, and Nathaniel. Your love and understanding helped this dream come true.

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Introduction

Yellow starthistle (*Centaurea solstitialis* L.) is a non-native invasive plant of North American rangelands, native to southern Europe. As with many non-native plant species, one of the reasons for yellow starthistle's success is a lack of natural predators and diseases that could otherwise help control its densities.

Yellow starthistle is a successful competitor because it produces a large juvenile rosette during late fall to late winter, while developing a root system that allows resource use to a depth of 1.5 meters (m), when the plant initiates floral stems in June. The rosette and floral stems allow yellow starthistle to compete for light throughout its life cycle, while shading neighboring plants and hindering their growth. Yellow starthistle has the ability to survive very dry habitats, and produces a large amount of seedheads and seeds. (Thomsen et al.1989).

It is difficult to assign an exact monetary amount to the loss of rangeland and non-crop areas by yellow starthistle. However, Roche and Roche (1988) did estimate a total annual economic loss from yellow starthistle and three knapweeds to be $951,000 in the state of Washington.

It is well documented that infestations of yellow starthistle lower forage yield and quality, cause problems in forage crop harvesting, increase livestock and crop management costs, and reduce recreational and economic value of infested land (Di Tomaso, et al. 1999). In addition, yellow starthistle invasions reduce desirable forage for livestock and wildlife, displace native plants, and decrease native plant and animal diversity (Prather and Callihan 1991, Sheley and

Larson 1994). Yellow starthistle is also known to cause a lethal neurological disorder known as “chewing disease” when eaten by horses (Kingsbury 1964).

Previous studies of yellow starthistle have included herbicide applications, livestock grazing, plant competition, and biological control, to reduce ecological and economic impacts on infested land. For example, Larson and McInnis (1989a) found that by applying the herbicide picloram as part of a seedbed preparation for perennial grasses, yellow starthistle production was reduced the following growing season. When heavily grazed by livestock in an annual grassland setting, during late spring and early summer (during the bolting stage but before spines develop), resulted in major reductions in plant biomass, canopy size, and seed production. (Thomsen et al. 1993).

Biological control from insects, such as the weevil *Bangasternus orientalis* and the fly *Chaetorellia australis,* have shown some success in limiting further invasion of yellow starthistle (Turner et al.1994, 1996). These studies found the larva of these insects feed off the seeds being produced in the capitula (seed head) of the plant.

Recently, a study performed by Di Tomaso et al. (1999) found that a series of prescribed fires over three years reduced yellow starthistle establishment while maintaining or increasing native broadleaf plant cover, richness and diversity.

The underlying goal and implication from these types of studies is that with a reduction in yellow starthistle, and better management practices controlling the type and frequency of disturbance, native vegetation will replace yellow starthistle. Sheley et al. (1999) stated that vigorous stands of perennial grasses can limit reinvasion by yellow starthistle through competition for resources.

The overall objectives of this study were to analyze the ability of yellow starthistle to compete for soil moisture and nutrients with other vegetation in (1) the canyon lands of the Snake River and (2) under a controlled environment in a greenhouse.

The objective of the field study was to evaluate yellow starthistle seedhead production at different stages of succession in a bluebunch wheatgrass (*Pseudoroegnaria spicata*) – arrowleaf balsamroot (*Balsamorhiza sagitatta*)- sandberg bluegrass (*Poa secunda*) habitat type. Data were collected on soil depth, soil fertility and soil moisture from 18 macroplots that were classified into six early, six middle, and six late seral staged plots. This data were collected over two summer field seasons (2000 and 2001).

The objective of the greenhouse study was to measure the production of yellow starthistle under simulated plant competition. Yellow starthistle seeds were germinated and plants were grown at varying levels of Nitrogen (N), Phosphorous (P) and soil moisture.

Literature Review

Yellow Starthistle

Yellow starthistle is a non-native invasive plant found growing on the rangelands of North America. It is a winter annual forb that is indigenous to dry open habitats in southern Europe. It is believed that yellow starthistle was introduced into North America in the 1850s by European settlers, when its seed was unintentionally incorporated into crop seeds (Maddox 1981). Since that time, it has spread into several western states including California, Oregon, Washington, Montana, Nevada, and Idaho (Maddox 1981). By the mid-1980s, yellow starthistle had infested about 113,316 hectares in Idaho and it is estimated to be spreading at a rate of 2,800 hectares/year (Sheley et al. 1999, and Callihan et. al.1989).

Yellow starthistle can successfully invade a site due to its phenological characteristics. One characteristic of yellow starthistle is its ability to produce two types of seeds, pappus bearing and non-pappus bearing (Roche 1965, Roche et al. 1997). Yellow starthistle flowers produce approximately 85% pappus bearing seeds and 15% non pappus bearing seeds (Benefield et. al. 2001). The pappus bearing seeds grow faster and are dispersed under optimum conditions in late summer, while the non-pappus bearing seeds stay in the seedhead longer, dropping below the parent plant, perhaps allowing for reproduction under less optimum conditions (Roche 1965, Maddox 1981, Roche et al. 1997).

Roche (1965) showed that dispersal by wind had an average distance of 4.88 meters from the host plant. He also noted that a variety of bird species feed on these seeds after dispersal. Therefore, long distance dispersals were probably caused by animal transport from birds, passing through their digestive system and later excreted, and/or by attaching to fur or hair of animals. Di Tomaso (2001) reported that additional seed dispersal over long distances could result through the transportation from vehicles and mechanical equipment.

Another aspect of yellow starthistle's competitive ability is its germination characteristics. Once seeds are dispersed from the host plant, and come in contact with the soil, they are able to take advantage of precipitation in the fall and/or winter and germinate within one week (Roche et al. 1997, Benefield 2001). In addition, Callihan et al. (1989) reported that yellow starthistle seedlings emerge almost immediately after the onset of late fall rains. Thus, no dormancy period is required for germination (Benefield et al. 2001). However, Di Tomaso (2001) stated that unpublished research performed by Enloe shows yellow starthistle germination occurs within a limited temperature range. This suggests an adaptation that prevents germination at the wrong time of year.

The rosette phase of yellow starthistle experiences growth through the winter and allows the plant to capture resources when other species are dormant or potentially growing more slowly. After this long rosette phase, yellow starthistle bolts during late May to early June (Maddox 1981, Roche et al. 1997). It flowers in July to early August and produces mature seed soon after (Maddox 1981, Callihan et al. 1989, Di Tomaso et al. 1999). This late season growth pattern occurs after many of the bunchgrasses (e.g. Bluebunch wheatgrass (*Psuedoroegnaria spicata)*) have gone dormant for the season (Roche et al, 1997). This growth pattern reduces competition from the bunchgrasses and during years of below average precipitation, and may reduce soil resources for the bunchgrasses the following growing season.

Yellow starthistle has a high light requirement for growth. Roche (1965), and Roche et al. (1994) reported that yellow starthistle is unable to grow on north facing slopes south western Washington based in part on the lack of sunlight. Consequently, yellow starthistle is generally found on south facing slopes. In addition to lack of light on north slopes, Roche et al. (1994) state that the lack of irradiation from the sun limits the temperature requirements for germination and for growth of leaves in the rosette phase. This lack of light and heat reduces yellow starthistle's growth potential and its ability to access resources.

One of the most important growth characteristics of yellow starthistle is its root development. Immediately after germination, most of the soil resources that this plant accumulates goes to the development of roots (Roche et al, 1994). Larson and Sheley (1994) found that yellow starthistle root depths are nearly twice the length of annual grasses, such as cheatgrass (*Bromus tectorum*). Therefore, even during years of high precipitation, low available moisture conditions can be created near the surface by such annual grasses. However, yellow starthistle has the ability to penetrate roots deeper into soils, allowing for niche differentiation with cheatgrass, resulting in the avoidance of interspecific competition with annual grass communities. In addition, in areas of high annual grass densities, the early spring growth that many annual grasses exhibit, removes surficial soil moisture, reducing available moisture for later maturing perennial bunch grasses that have a similar root depth to the annual grasses.

Sheley and Larson (1995) quantified the interference relationship between cheatgrass and yellow starthistle at three different soil depths (unrestricted, 0.5 m, and 0.2 m). Their results found a strong interaction between soil depth, interspecific, and intraspecific competition. In the unrestricted soil depths, there was a maximum predicted output of an isolated yellow starthistle plant to produce 1,446 seeds per individual yellow starthistle plant. With a 10-fold increase in yellow starthistle density their data indicated a reduction to about 100 to 300 seeds per plant, thus resulting in a strong intraspecific affect. An increase in cheatgrass density in unrestricted soils had much less effect on yellow starthistle seed production then did intraspecific competition. However, on soils restricted to 0.2m, cheatgrass interference was two times greater than intraspecific interference in determining yellow starthistle shoot weight. They concluded by stating, “the shallow fibrous rooting system of cheatgrass appeared to be better suited for resource capture in shallow soils. Conversely, yellow starthistle had an advantage over cheatgrass in deep soils where taproot development enabled continued resources uptake (e.g. soil moisture) and increased seed output when adequate deep moisture was available”.

Sheley and Larson (1997) analyzed the effects of densities, and soil depth on the growth rate and duration of growth on yellow starthistle and cheatgrass. At low yellow starthistle densities, yellow starthistle grew more rapidly, for longer time periods, and had greater soil depth penetration then cheatgrass. They also found that in deep soil and low yellow starthistle density, yellow starthistle's growth rate was seven times faster then cheatgrass. However, when cheatgrass and yellow starthistle where grown together in shallow soils (0.2 m), growth rates were reduced, which allowed for soil resource acquisition to favor cheatgrass over the later maturing yellow starthistle. This implies that yellow starthistle and cheatgrass infestations will increase resource utilization, and in areas of deep soils, resource partitioning can be fully developed. They concluded by stating, “we speculate that yellow starthistle has the potential in deep soil to grow faster and sequester more resources than most perennial grass seedlings”.

Another study by Sheley et. al. (1993) on plant competition with yellow starthistle consisted of growing yellow starthsitle, hedgehog dogtail grass (*Cynosurus echinatus*), and medusahead (*Taeniatherum caput-medusae*), from seeds collected from plants grown in association in southwestern Oregon, and from purchased seeds of orchardgrass (*Dactylis glomerata*), and subteranuem clover (*Trifolium subterraneum*). They discovered yellow starthistle roots grew more rapid, longer and for longer periods of time then the other species. As a result, yellow starthistle would be able to utilize resources, such as soil moisture, when it may not available for the other species. Hence, this is why yellow starthistle is able to continue its growth cycle later in the season after most species have become dormant. This same study also found that of the plants grown in conjunction with yellow starthistle, subterranean clover (*Trifolium subterraneum*) had the most similar root growth pattern as yellow starthistle, and may be a good species to use when reseeding rangelands that are not currently dominated by yellow starthistle. However, the use of subterranean clover to reduce yellow starthistle abundance in areas where yellow starthistle dominates may not be effective *because* of their similar growth patterns. Even though these two species have similar growth patterns it is believed that yellow starthistle would out-compete the clover because of its faster root growth. Therefore, sites dominated by yellow starthistle would remove resources before subterranean clover could be established.

Further information on the ability of yellow starthistle to be a successful competitor with other vegetation based on root development have been analyzed by Roche (1965) and Roche et al. (1994). Roche (1965) found that yellow starthistle invading a stand of bluebunch wheatgrass was able to remove moisture that would otherwise be available for bluebunch wheatgrass later in the season during its bolting phase. Thus, bluebunch wheatgrass must rely on precipitation later in the season and precipitation the rest of the year in order to allow for continued growth, or for new plants to emerge. Roche et al. (1994) stated that if bluebunch wheatgrass is grazed too heavily when competing with yellow starthistle, particularly later in the season, there may be little to no moisture available in the soil to allow for regrowth.

Additional studies have been performed to analyze the competitive nature of yellow starthistle with other vegetation. It has been shown that for yellow starthistle to grow, produce seedheads, and out compete other plants, the moisture must be available deeper in the soils. Sheley and Larson (1994a) found that during dry springs, yellow starthistle’s seed production was severely reduced. There was a 25% reduction of juveniles reaching the adult stage, and only 25% of the individuals that reached adult stage survived to produce a limited number of seeds. They concluded that in dry springs, moisture did not percolate to lower depths, and therefore was not available later in the season.

Other studies have grown vegetation in association with yellow starthistle to discover which species can best compete. One study by Larson and McInnis (1989) planted diffuse knapweed (*Centaurea diffusa*) and yellow starthistle in association with four perennial grasses (covar fescue *(Festuca ovina)*, 'Ehpraim' crested wheatgrass *(Agropyron cristatum)*, 'Critiana' thickspike wheatgrass *(Psuedoroegnaria dasystachyum)*, and 'Paiute' orchardgrass *(Dactylis glomerata)*). Survival of yellow starthistle in a grass stand depends upon the ability of the grass species to occupy the site and have access to available soil resources. According to their findings, 'Paiute' orchard grass plots were the most productive and best at reducing the number seedlings of both *Centaurea* species. They concluded that it was critical for these grass species to remove soil moisture and nutrients from the rooting zone and overlap the active growth period of the *Centaurea* species.

Borman et al. (1991) evaluated the abilities of selected perennial grasses to suppress annual plants. They found that when perennial grasses, such as 'Berber' orchardgrass and Idaho fescue *(Festuca idahoensis)*, were established prior to yellow starthistle invasion, these grasses were most effective at suppressing yellow starthistle because of their ability to initiate growth even earlier then yellow starthsitle and maintain growth through the winter.

A follow up study by Borman et al. (1992) more closely analyzed the ability of annual and perennial grasses, along with yellow starthistle, to extract soil moisture. Annual grass plots left the highest amount of residual moisture in the soil when compared to plots dominated by perennial grasses or yellow starthistle. Therefore, it was inferred that the residual moisture left after annual grasses completed their growth cycle, would be available for later maturing species, such as yellow starthistle. However, sites established by early growing perennial grasses with an extended growing season may preclude niche availability for yellow starthistle by reducing residual soil moisture (Borman et al. 1992). They also concluded that later growing perennial grasses, such as wheatgrasses, did not have an advantage for accessing soil moisture when in competition with annual grasses and yellow starthistle simultaneously, due to annual grasses accessing the early season moisture, and yellow starthistle removing the remaining soil moisture throughout the season.

It is assumed that competition between yellow starthistle and other vegetation will reduce the plant's ability to produce viable seeds and reproduce. Pitcairn et al. (1997) planted varying densities of yellow starthistle in conjunction with varying densities of other plants growing in a study area located in Solano County, California. This study suggested that at yellow starthistle densities lower than 400 plants per square meter produced fewer seedheads when it experienced competition from other plants (interspecific competition), as opposed to stands of yellow starthistle that only experienced intraspecific competition.

Plant Competition for Soil Resources

The concept of change in vegetation community structure over time, commonly referred to as succession, has been around for over 100 years (Burrows 1980). A major aspect of succession is the dynamics of plant competition for resources. Many studies have suggested that the availability of soil resources, such as nitrogen, phosphorus, and water, may influence successional dynamics (Tilman 1986).

It is believed that the amount of resources, and a plant's ability to compete for these resources in order to meet the requirements needed for survival, determines the type of plants that survive, and the community structure that persists. For example, Parrish and Bazazz (1982) reported on plant response from successional communities to nutrient gradients. They suggested that early successional plant species inhabit a site first in part because of their fast growth and ability to use nutrients first. Thus, early successional plant species generally have a wider range of tolerance to nutrient concentrations when compared to mid and late successional species.

Tilman (1986), performed a similar study on the ability of early seral species to use nitrogen (N), on soils low in N in Minnesota. He found that early successional plants can extract more N and grow more rapidly even in N poor soils than late successional species. Therefore, early successional species may be superior competitors for soil N when compared to later successional species.

Although early seral species may be able to more effectively extract N when compared to later successional species, soil low in N may not be optimum growth for early seral species. McLendon and Redente (1994) summarized from other sources that early seral species, mainly annuals, may dominate sites by rapidly utilizing resources needed for slower growing species. The early seral species may dominate a site as long as they can maintain their high production. However, early seral species require high soil nutrient levels. If soil nutrients are reduced below the requirements for early seral species, plant species with lower nutrient requirements will have a competitive advantage and will begin to dominate. McLendon and Redente's study tested the hypothesis that if nutrients, particularly N, were added to a system undergoing secondary succession, the rate of succession would be reduced and that early seral species would dominate longer than normal. Therefore, with a decrease in N availability, succession would increase. The conclusions of their study affirmed this hypothesis. They stated that an increase in N availability slows the rate of succession, and that annuals dominate because they grow more rapidly and can therefore accumulate nutrients and perhaps moisture more quickly than perennials. One caveat to their findings was the influence of cheatgrass on the system. The presence of cheatgrass was able to extend dominance of annuals because of its low N requirements, early growth characteristics, and ability to use soil moisture. This influence is particularly important in areas where resources, especially soil moisture, are not available to plants for much of the warm season.

Competition for resources from species like cheatgrass not only has an effect on successional changes and community structure, but also on species competing for the same resources where niche overlap occurs. For example, Wilson and Tilman (1991) found that plant species grown in direct competition (across a gradient of N availability) had a reduction in above and below ground biomass at all varying levels of N availability as compared to plants grown without competition.

A similar study by Pickett and Bazazz (1978) using soil moisture as a gradient to study plant production, found plants that experienced water stress had definite changes in growth structure, but did not experience high mortality. Therefore, competitive and gradient stresses were generally absorbed through plasticity.

Hull (1964) found that when cheatgrass and various wheatgrass species were grown together, there was a significant reduction in above ground growth and root growth of the wheatgrass species and very little effect on cheatgrass.

All these studies point out that with plant competition there is a reduction in available nutrients and moisture, thus causing a change or reduction in plant production or morphology. However, it is possible that even when plant competition exists and nutrient concentrations are high, certain species may not perform well. A study on responses of three successional communities to a nutrient gradient by Parrish and Bazazz (1982) reported that mid- and late successional species had few survivors at high concentrations of nutrients, perhaps due to the low nutrient requirements needed for these species. However, mid- and late successional plants that were able to tolerate the high concentrations of nutrients grew quite large and could exploit the resources available under reduced competition.

Although yellow starthistle is classified as an annual species, it has a long growth period allowing it to compete for moisture and nutrients later in the season with slower growing - late successional species, such as bluebunch wheatgrass, arrowleaf balsam root, sandberg bluegrass, which are typical of south facing slopes in the Snake River Canyon in Idaho.

Methods

Site Description

The study area for this project is located at the Garden Creek Preserve, approximately 50 km south of Lewiston, Idaho. This site is located in Idaho near the conjunction of Washington, Oregon, and Idaho. The study area is bordered by the Snake River to the west, the Craig Mountains to the east, Cave Gulch Creek to the south, and open canyon lands to the north. Corral Creek flows east to west, bisecting the study area. The topography of the area is characterized by broad flat plateaus intermixed with steep walled canyons. The canyons are estimated to be approximately 1220 meters deep and created by a combination of uplift and erosion (Lewis County Soil Survey, unpublished). The underlying parent material consists of basalt and outcrops can be seen in several locations.

The canyon lands have been identified as non-forested rangelands by the Nez Perce – Lewis Counties Soil Survey. The climax vegetation of the canyon rangelands, as identified by the Perce-Lewis Counties Soil Survey, consists of bluebunch wheatgrass (*Pseudoroegnaria spicata*)-sandberg bluegrass (*Poa secunda*). The plant communities consist of 70-80% grasses, 10-15% forbs, and 5% shrubs.

The soils of the study area consist of the Kettenbach – Gwin complex and the Limekiln – Crowers association. The Kettenbach-Gwin complex is found on 35-75% slopes and has fractured basalt parent material. The Kettenbach soil is found on south facing slopes and consists of stony silt loam to very gravelly silt loam from 25.4-63.5 cm deep to parent material. The Gwin soil is found on ridges and convex slopes and consists of a very stony to gravelly silt with an average depth to parent material of 30.5 cm. The ecological sites associated with the Kettenbach and Gwin soils are bluebunch wheatgrass / arrowleaf balsamroot (*Balsamorhiza sagittata*), and bluebunch wheatgrass / sandberg bluegrass, respectively.

The Limekiln – Crower association is found on 45-80% slopes. The Crower soils are generally located on north facing slopes, are up to 157.5 cm deep, and are dominated by an Idaho fescue/bluebunch wheatgrass plant community. Since this study focused on south facing slopes, it is believed that the Crowers soil consisted of less then 5% of the study plots. The Limekiln soil is found on south facing slopes, and is characterized by a stony to extremely gravelly silt loam down to 40.5cm in depth, where it meets a basalt parent material. The natural plant community for the Limekiln soil is a bluebunch wheatgras/plains prickly pear (*Opuntia polycantha*) association (USDA, NRCS, unpublished)

This area was chosen because it is not currently grazed by livestock (although it has a history of cattle and sheep grazing) and has a complex of sites with varying successional stages. Yellow starthistle has invaded mainly southern aspect slopes of the canyon in the bluebunch wheatgrass-sandberg bluegrass – arrowleaf balsamroot habitat type.

Field Methods

Data collected on the production of yellow starthistle seedheads and were compared to soil depth, amount of nitrogen (N) and phosphorous (P), and soil moisture content across early, middle, and late seral stages. Eighteen macroplots (25 X 25 m) were selected from the within the habitat type - six late seral, six mid seral, and six early seral. Criteria and locations of early, mid, and late seral stage macroplots were previously identified in this area by Robins (2001 MS thesis) for research concerning the invaisibility of yellow starthistle. Percent canopy cover of yellow starthistle was stratified as having an average of 31.5% for early seral plots, 2.19% for mid seral plots, and 0.57% for late seral plots.

One 20 meter transect was located within each macroplot for soil data collection. Five to ten sub-sample locations were randomly selected off the transect. A 15.25 cm X 5 cm hand soil sampler was used to collect soil samples. The sampler was driven into the ground, until the sampler was refused by parent material. Ten to 15 sub-samples from each macroplot were composited into one sample, placed into sample bags and analyzed at the University of Idaho's analytical soil lab for plant available nitrogen (2M KCL method), and plant available phosphorous and potassium using the Morgan extraction method (0.75N and NaOAC). Available moisture percent and pH were also tested.

Soil depth was measured with a hand tape, and recorded at each sub-sample location in each macroplot.

The step-point transect (BLM, 1985) method was used to collect seedhead data. A transect was located through the middle of the macroplot. At every second step the yellow starthistle plant closest to the point of the boot was counted for number of seedheads per plant. A minimum of ten plants were counted per plot. The fieldwork was performed over two summer seasons in 2000 and 2001.

Seral Plot Locations

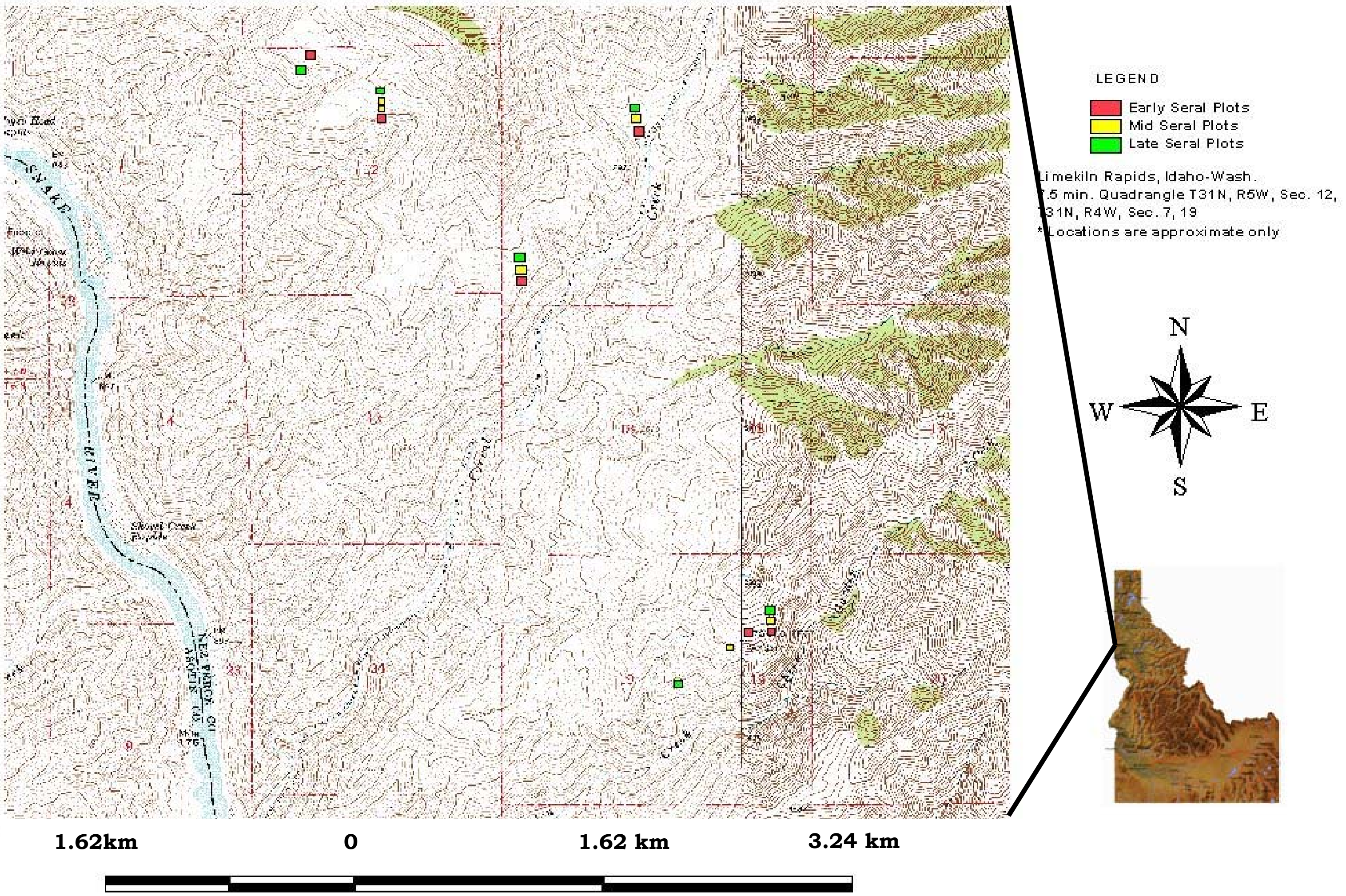

Figure 1. Topographic map of study plot locations, near Craig Mountain, ID

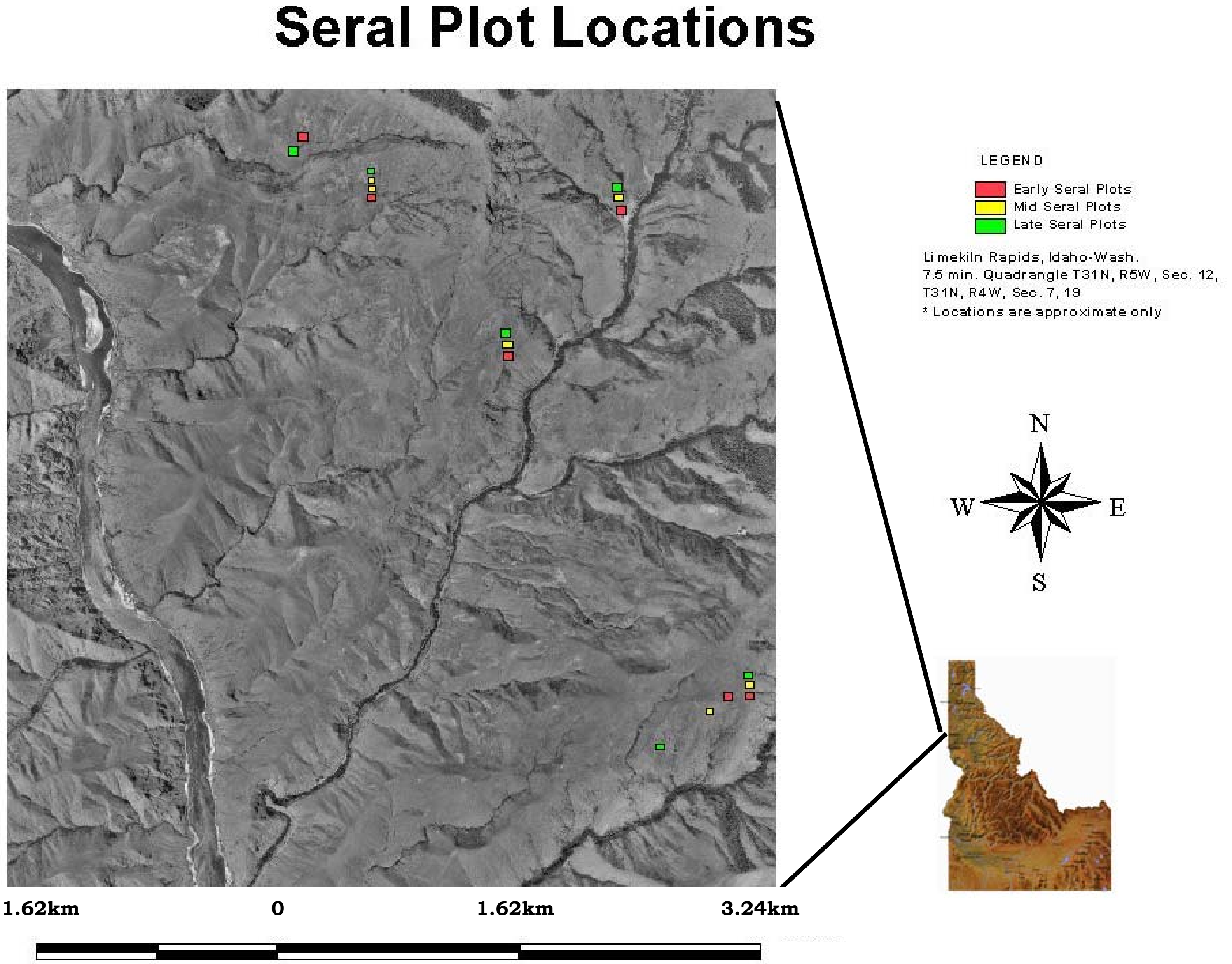

Figure 2. Aerial photograph of study plot locations, near Craig Mountain, ID

Greenhouse study

Since the Garden Creek Preserve has been treated with biological control agents to reduce the invasion of yellow starthistle, a greenhouse study was performed under controlled conditions to assist in gathering seedhead production data. Two greenhouse studies were designed to analyze the effects of soil fertility and moisture content on yellow starthistle production.

The first study (phase A) was done in order to simulate plant competition for water and nutrients. This phase was performed in two trials (trials 1 & 2). The number of plants that germinated and the number of seedheads produced per plants were recorded at varying levels of soil moisture percent, nitrogen (N), and phosphorous (P). Competition for soil nutrients focused on N and P, and excluded potassium (K), because K is generally not considered a limiting factor on rangeland soils.

Fifteen yellow starthistle seeds were planted in three gallon pots. The potting medium consisted of 1/3 perlite, and 2/3 all purpose sand mixture. The plants were grown under varying levels of water and nutrient supply at 23 degrees C, with 16 hours of light and 8 hours of dark. The study was laid out as a completely randomized factorial design and replicated four times (see Table 1).

The high levels of N added to the soil medium was 34% (ammonium nitrate) at the equivalent of 134.52kg/ha (120 lbs./acre). The low levels of nitrogen added to the soil was 34% as ammonium nitrate, at the equivalent of 16.81kg/ha (15lbs/acre). The high levels of Phosphorous added was 44% at the equivalent of 67.26kg/ha (60lbs/acre). The low level of phosphorous was 44% at the equivalent of 8.97kg/ha (8lbs/acre). All pots were given a one time treatment of micronutrients. The soil was treated with nutrients and then watered to moisture percentages of 30, 20, 10, and 5 based on volume weight. Seeds were added to the soil approximately 72 hours after adding nutrients and water. The number of plants that germinated and the amount of seedheads produced were recorded at each treatment level. After germination plants were thinned to one plant per pot.

Water	30%	20%	10%	5%
Nutrients	N_{H},P_{L}	N_{H},P_{L}	N_{H},P_{L}	N_{H},P_{L}
	N_{H}, P_{H}	N_{H}, P_{H}	N_{H}, P_{H}	N_{H}, P_{H}
	N_{L}, P_{L}	N_{L}, P_{L}	N_{L}, P_{L}	N_{L}, P_{L}
	N_{L}, P_{H}	N_{L}, P_{H}	N_{L}, P_{H}	N_{L}, P_{H}

Table 1. N – Nitrogen, P- Phosphorous, $_{H}$ – high levels, $_{L}$ - low levels, each cell above represents one pot. Water percentages are based on volume weight. These treatments were replicated 4 times and the study was repeated.

The second study (phase B) was designed to analyze the ability of yellow starthistle to germinate across a range of nitrogen levels. For phase B of the greenhouse study, three gallon pots were filled with a mixture of 1/3 perlite, and 2/3 all purpose sand soil mixture. Pots were treated with varying levels of nitrogen, a single level of phosphorous, and watered to (and maintained at) 20% moisture content. The phosphorous treatment was an equivalent of 8.97 kg/ha (44%). The levels of nitrogen (34% as ammonium nitrate) were 224.2 kg/ha (200 lbs./A), 179.36 kg/ha (160 lbs./A), 134.52 kg/ha (120 lbs./A),89.68 kg/ha (80 lbs./A),44.84 kg/ha (40 lbs./A), and 0kg/ha(0 lbs./A). The nitrogen was dissolved in water and then added to the pots. A total of 40 seeds per pot were added 72 hours after nutrient and water treatments. This phase of the study was replicated four times.

Analytic Procedures

The computer program SAS (1999) was used to analyze the results of the data gathered. Field data on seedhead production was collected from three seral stages (early, middle, and late) over two seasons. The General Linear Model (GLM) procedure, and a Tukey studentized t-test (alpha = .05) of the means from the different seral stages were used to analyze differences across the seral stages. Additionally, the same procedures were used to analyze differences in independent variables of soil depth, soil fertility, and soil moisture percentage from the dependent variable of the three seral stages for data collected during the summer of 2001.

Analysis of variance (ANOVA) and Tukeys studentized t-test (alpha=.05) was used to evaluate the significance of effects on the dependent variables of germination and seedhead production from the independent variables of fertility treatments, percent moisture treatments, and interaction between treatments. Seedhead and germination results were transformed in the SAS code using a square root transformation to achieve homogeneity of variance in the data. Variables and interaction between variables were tested for significance. Those variables and interactions that lacked significance were removed from the model, until only the significant variables remained. A graph of the residuals versus normal quantiles was produced which showed that the residuals are generally normally distributed.

Since there was no significant effect from the replications nor interaction between the trials 1 and 2 from phase A of the greenhouse study, the data from trials 1 and 2 were combined for statistical analysis.

Results and Discussion

Field Study

Seedheads from yellow starthistle plants were collected across three categories of seral stages (early, middle and late) over two field seasons (summer of 2000 & 2001). For the 2000 growing season yellow starthistle plants had an average of 1.75 seedheads per plant in the early seral stage plots. The middle seral stage plots had an average of 1.85 seedheads per plant, and the late seral stages had an average of 1.75 seed heads per plant. An Analysis of Variance (ANOVA) was performed on this data and showed that there was no statistical difference between the means (P=.9563) (figure 3). For 2001, seedhead production averaged 2.24, 2.63, and 2.60 seedheads per plant for the early – middle – and late seral stages, respectively. The ANOVA showed that there was no statistical difference between the means across seral stages (P=.6501) (figures 3 and 4). There was no significant difference in seedhead production when comparing seral stages from the 2000 season to 2001 season (P=0.2861).

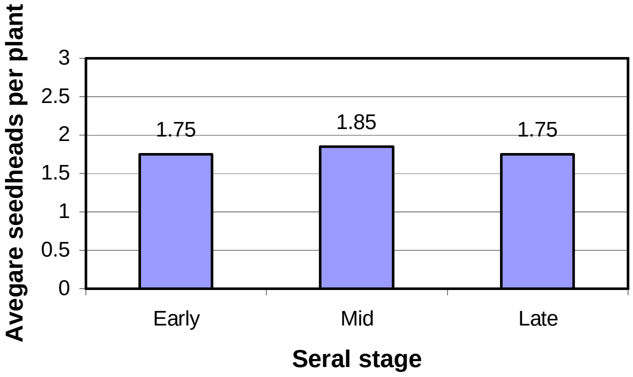

Figure 3. Average number of seedheads per plant across seral stages-2000 season. There was no significant difference between stages.

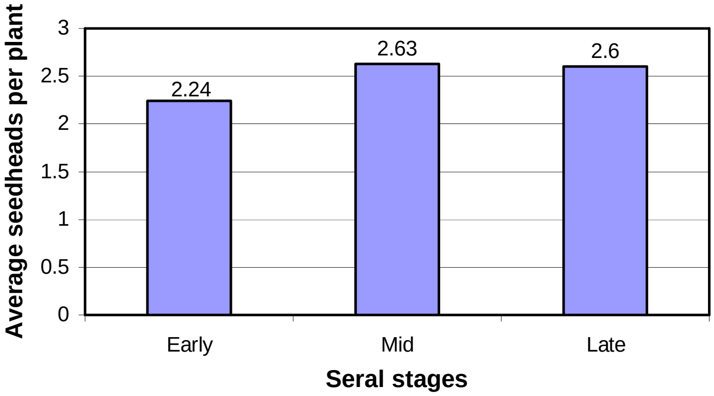

Figure 4. Average number of seedheads per plant across seral stages – 2001 season. There was no significant difference between stages.

Soil data and samples were taken from the differing seral stages from the 2001 season. Soil depth, soil moisture, and levels of soil N and P were measured and tested to analyze their effect on seedhead production across seral stages. Neither soil depth, soil moisture percentage, nor levels of N and P had a significant effect on average seedhead production (P=0.548, P=0.132, P=0.386, P=0.308, respectively, see Table 2).

Table 2. The effects of soil depth, soil moisture, and levels of N and P on yellow starthistle seedhead production, across seral stages-2001 data.(∝=0.05) (SAS. 1999)

```
Dependent Variable: average seedhead count across seral stages

                                            Sum of
 Source                      DF            Squares     Mean Square    F Value    Pr > F
 Model                        6         8.24690816      1.37632313       2.18    0.1411
 Error                        9         5.68405295      0.63150662
 Corrected Total             17        13.93096111

              R-Square     Coeff Var      Root MSE    Mean # of seedheads
              0.591984      34.72758      0.842916        2.427222

 Source                      DF        Type III SS     Mean Square    F Value    Pr > F
 Seral stage                  2         4.54464340      2.27232170       2.90    0.1054
 Soil depth                   1         0.27841220      0.27841220       0.39    0.5488
 nitrogen                     1         0.59603206      0.59603206       0.84    0.3865
 phosphorous                  1         0.84231354      0.84231354       1.19    0.3079
 moisture                     1         1.99344669      1.99344669       2.81    0.1325
```

Soil depth, moisture, and N & P levels were tested to see if there were differences at early-, middle-, and late - seral stages. There were no differences in moisture percentages (P=0.089), N (P=0.721), and P (P=0.378) levels across seral stages. Since there was no significant difference in soil moisture, N, and P the average of these factors was calculated across seral stages. In contrast, soil depth was significantly different across seral stages (P=0.009). Early seral stage plots had an average soil depth of 39.34 cm, middle seral plots had an average of soil depth of 21.79 cm, and late seral stage plots had an average soil depth of 16.81 cm (figure 5).

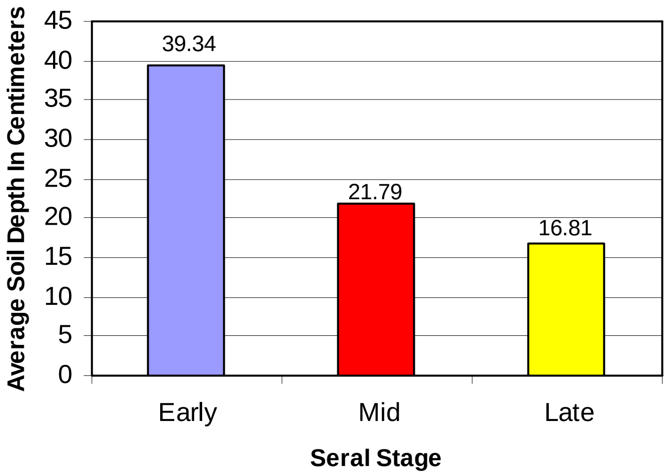

Figure 5. Average soil depth across seral stages.

Although there was no significant difference in seedhead production of yellow starthistle across the seral stages from both field seasons, yellow starthistle appeared to have its highest densities in early seral plots and lowest in late seral plots. Densities across the various seral plots were calculated from yellow starthistle data collected by Robbins (2001 MS Thesis). Mean densities per m^2 were 15.83, 5.63, and 0.27 for early-mid-late seral plots, respectively . The high density production of yellow starthistle in early seral plots appeared to be correlated to the deeper soils of the seral plots. Therefore, deeper soils tended to favor yellow starthistle establishment. However, with an increase in yellow starthistle densities, there appeared to be low production of individual seedheads per plant. The low production of seedheads per plant may have been caused by intraspecific competition.

In the mid and late seral plots, there was a significant reduction in soil depth. Yet, there was no difference in seedhead production of yellow starthistle at these seral stages. Therefore, the shallow soils of the mid and late seral plots may have allowed for soil resources to be shifted away from the deep rooting yellow starthistle and towards shallower rooting plant species, thus causing interspecific competition.

These results appear to be consistent with Sheley and Larson (1995 and 1997) who reported a reduction in yellow starthistle growth and individual seed production in restricted soil depths.

Greenhouse Results

Germination Trial Results

Analysis of variance (ANOVA) was used to analyze the effect of varying levels of soil fertility (N and P) and percent moisture on yellow starthistle germination (germination trial – phase A). Results of this analysis were N ($P<0.001$), moisture percent ($P=0.001$) and an interaction of nitrogen and percent soil moisture ($P=0.002$) had significant effects on yellow starthistle germination, whereas phosphorous levels had no significant effect on germination ($P=0.824$).

A Tukey studentized t-test grouping analysis on nitrogen levels separated high and low levels of nitrogen into two groups. These results showed that low levels of N had a significantly higher amount of germination than high levels of N.

In general, higher levels of moisture percentages (30% and 20%), had a higher amount of germination than 10% and 5% moisture percentages at both levels of N (high and low) (figure 6). However, 30% moisture at high N had a significantly higher germination than 20%, 10%, and 5% moisture levels at high N. Whereas at low N, there was no significant difference between 30% and 20% moisture.

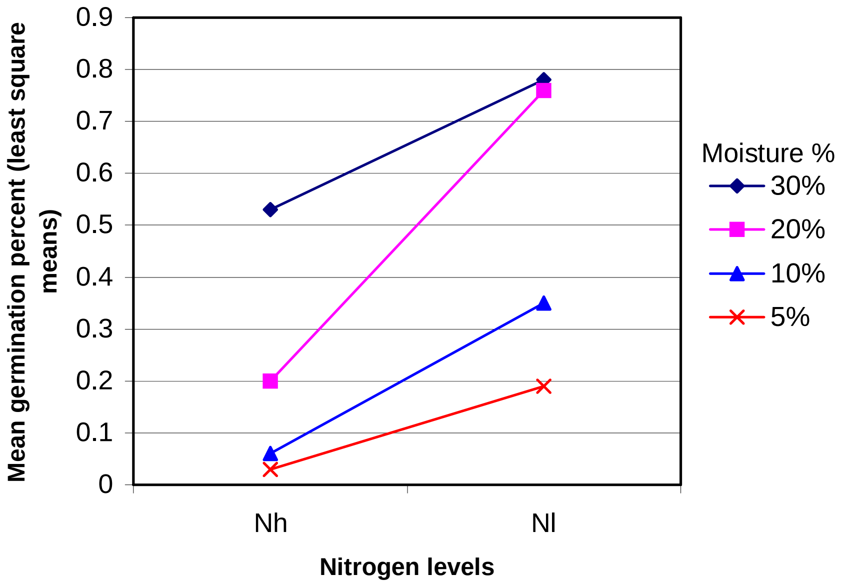

Figure 6. Percent yellow starthistle seed germination relative to nitrogen levels and moisture percentages.

Although there is some interaction between levels of N and percent moisture, the general trend was that lower levels of N combined with high percentages of moisture produced the highest amount of germination.

Since high levels of N appeared to suppress yellow starthistle germination, a second germination trial was performed at varying levels of N (phase B). The range of nitrogen levels added to the pots was an equivalent of 224.2 kg/ha, 179.36 kg/ha, 134.52 kg/ha, 89.68 kg/ha, 44.84 kg/ha, and 0 kg/ha. Soil moisture percentage and phosphorous levels were kept at a constant level of 20% and 8.97 kg/ha, respectively. This resulted in germination of yellow starthistle seeds steadily increasing as nitrogen levels decreased (figure 7).

Based on the results of this trial, the varying levels of N had a significant effect on germination (P<0.001).

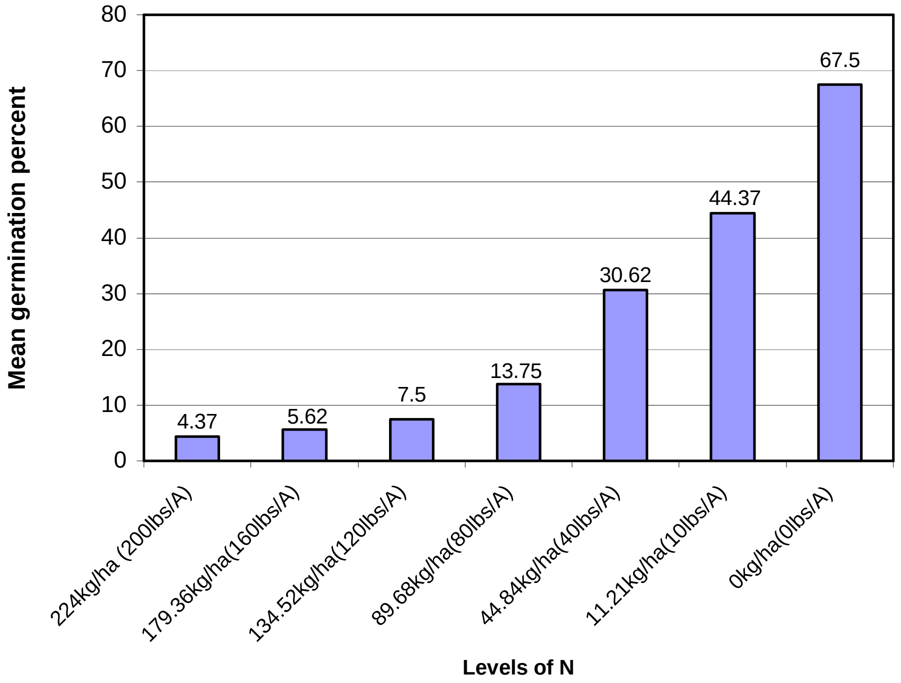

Figure 7. Mean percent of seeds that germinated at varying levels of nitrogen applications.

Seedhead trial results

The number of yellow starthistle seedheads per plant, were counted from those pots that produced a plant. In general, there was a difference among moisture treatments in conjunction with fertilization treatments. Moisture levels of 5% and 10% were not significantly different between each other at all fertility treatments (P≥0.999). Moisture levels of 5% & 10% were significantly different from 20% & 30% moisture levels across fertility treatments, with the exception of the NhPl (N high/P low) fertility treatment. There was a significant decrease in seedhead production from the NhPh (N high/P high) to NhPl at the 20% moisture level (P=.0003). However, at NhPl the 30% moisture level produced significantly higher amounts of seedheads than 5% & 10% (P=.0003), as well as at the 20% moisture level (P=0.001)

At the NlPh (N low/P high) 20% moisture treatment level, there was an increase in seedhead production (although not significant). Seedhead production at NlPh-30% moisture continued a downward trend (although not significantly different than NhPl, it was significantly lower than the NhPh level, P=.0004).

At the low nitrogen/low phosphorous (NlPl) level there was a reduction in yellow starthistle seedhead production at 20% and 30% moisture content. This reduction was significantly different at the 20% moisture level when compared to NlPh (P=.0003). The reduction in seedhead production was not significant at the 30% moisture level ranging from NlPh to NlPl. However, there was a significant difference between NlPl at 30% and 20% moisture, when compared to NhPh at 30% and 20% moisture content (P≤0.0001) .

Although these data indicates that there was an interaction between fertility levels and moisture levels, there was a general reduction trend in yellow starthistle seedheads with the reduction in either nitrogen or phosphorous or soil moisture percent, or a combination of all of these factors.

Parrish and Bazazz (1982) stated that mid- and late- successional species have reduced survivorship at high nutrient concentrations. Their report indicates that a cause of mortality could be due to low nutrient requirements for mid and late species. Yet, the plants that did tolerate high nutrient concentrations were able to exploit the available resources. Although yellow starthistle is an annual plant that is considered an early successional species after disturbance (e.g. fire, poor livestock grazing management) in this habitat type, it has a later maturing growth pattern that matches many of the perennial species that are considered late - seral species. The germination trial indicated that with an application of nitrogen to the soil, yellow starthistle seeds had reduced germination. However, the greenhouse seedhead data found that of those seeds that germinated and survived the highest concentrations of N, they were able to grow to maturity and produce the highest numbers of seedheads. Therefore, these findings appear to be consistent with those reported by Parrish and Bazazz (1982).

Results from this trial found that the highest production of yellow starthistle seedheads (of those plants that germinated) were recorded at high nitrogen and high phosphorous fertility treatments at 20% and 30% moisture levels (no significant difference between moisture treatments, $P \leq 0.0001$). For all other combinations of lower levels of soil fertility and soil moisture, there was a downward trend in the ability for yellow starthistle to produce seedheads. Therefore, the reduction in available soil nutrients and soil moisture was perhaps simulating plants competing for these resources accounting for the negative effect on seedhead production (figure 8 and 9).

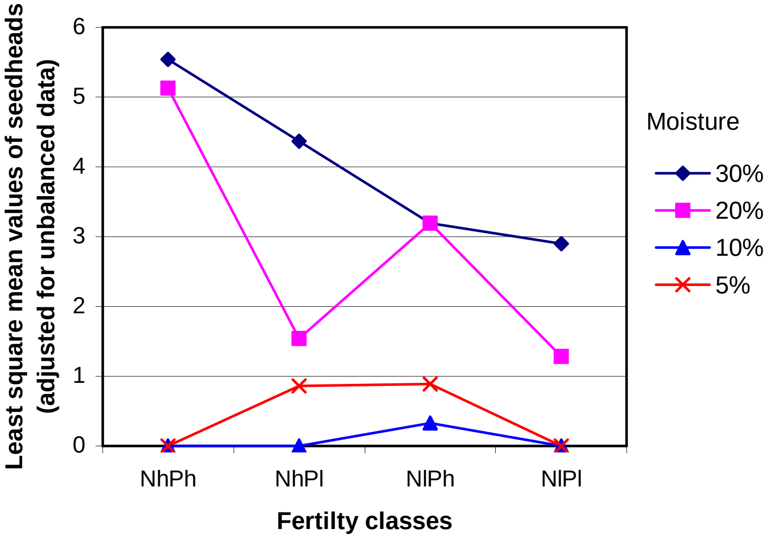

Figure 8. Mean values (least square) of yellow starthistle seedheads production based on levels of nitrogen, phosphorous, and moisture percentages.

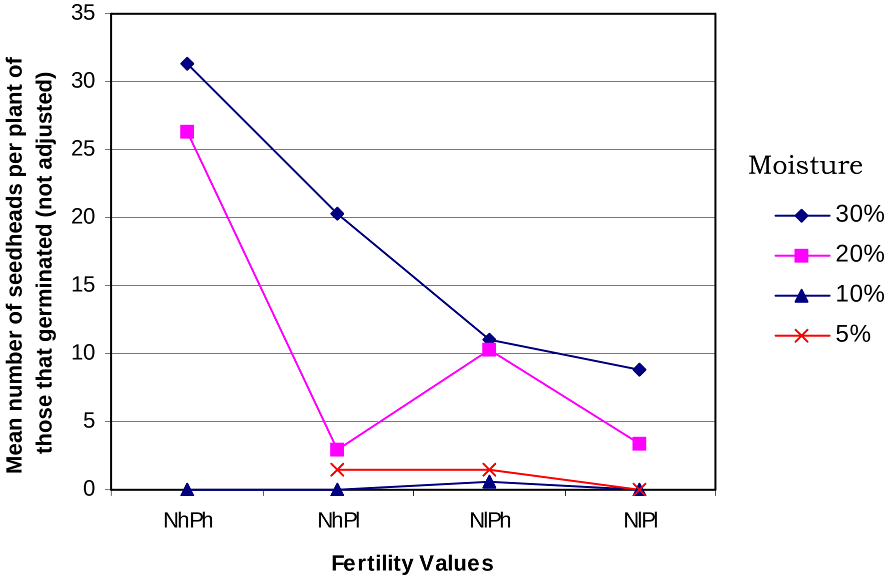

Figure 9. Actual mean (unweighted) number of seedheads based on levels of nitrogen, phosphorous, and moisture percentages.

A correlation between plant competition under greenhouse conditions and inter-intraspecific plant competition in the field is evidenced when comparing the level of soil nutrients, percent soil moisture and seedhead production of NlPh at 10% moisture from the greenhouse to field data results. Soil fertility and moisture of NlPh at10%, closely matched conditions found in the field, across all seral stages. Figures 10-12 display the relationship between the greenhouse and field conditions.

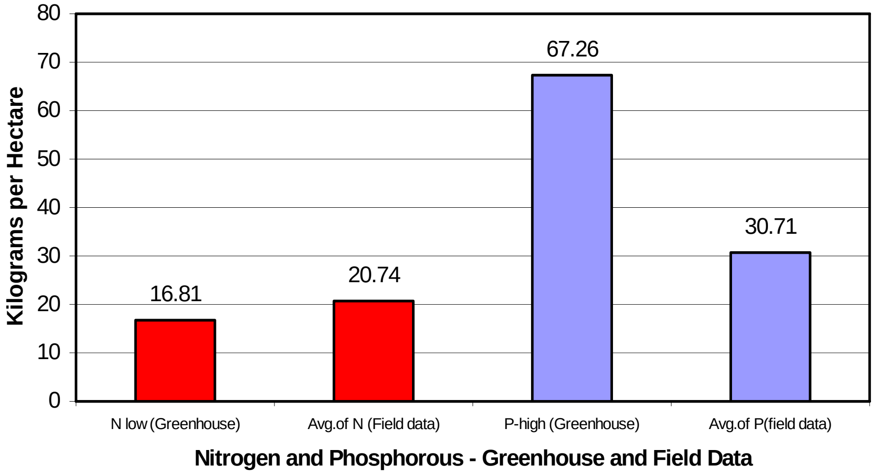

Figure 10. Relationship between greenhouse treatments and field data findings for nitrogen and phosphorous.

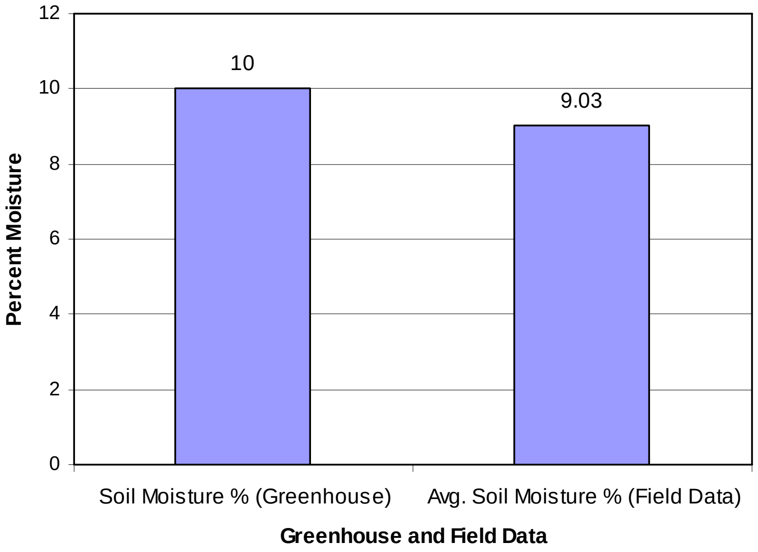

Figure 11. Relationship between greenhouse treatments and field data findings for soil moisture percent.

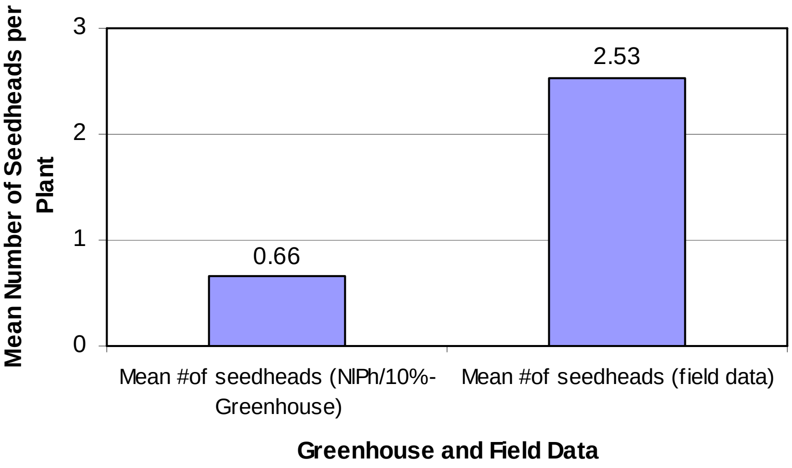

Figure 12. Relationship between mean number of seedheads produced in the greenhouse at NlPh-10% and mean number of seedheads produced in the field across all seral stages.

A two sample t-test was performed to test the difference between the means of the seedheads at NhPl-10% moisture and from the 2001 field data across seral stages. At the α=.05 level the means were significantly different, however the means were not significantly different at the α=.01 level ($.05<t_{0.05,204}<.01$, $t_{0.05,204}=2.23$). One factor for the difference in mean seedhead production could be caused by a higher initial moisture input from seasonal rainfall, whereas in the greenhouse, soil moisture was kept at a constant level of 10% throughout the lifecycle of the plant.

In contrast, the mean number of seedheads per plant produced in the field from 2000 (average range of 1.75-1.85 depending on seral stage) and 2001 (average range of 2.24-2.63 depending on seral stage) are far below the mean number of seedheads produced by plants grown in the greenhouse under conditions that did not experience simulated plant competition (NhPh-20%

moisture –average of 26.3 seedheads/plant and NhPh-30% moisture – average of 31.3 seedheads/plant) (figure 13).

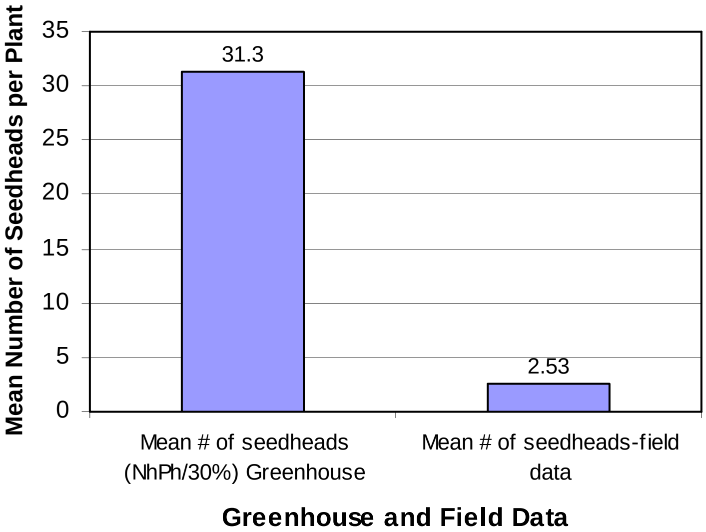

Figure 13. Comparison between mean number of seedheads from greenhouse at NhPh/30% (no simulated plant competition) versus mean number of seedheads from field data across seral stages (using 2001 data).

Conclusions

Fieldwork

There was no significant difference in soil moisture percentage and soil fertility. There was a significant difference in soil depth across seral stages. Based on yellow starthistle seedhead data collected from the 2000 and 2001 field seasons there was no significant difference in yellow starthistle seedhead production across seral stages. However, the average number of seedheads produced in the field for this study are below results that were reported for the average number of seedheads grown by Pitcairn et al. (1995) under varying plant densities.

Pitcairn, et al. (1995) found that yellow starthistle seedhead production at low plant densities, 1, 4, 12, 24 plants/m^2, production of seedheads/plant was approximately 150, 76, 65, 40, respectively. They concluded that an increase in plant density caused a reduction in seedhead production through intraspecific competition. However, soil depth was not a factor in their study.

Field data collected for this study found that across seral stages, over two years, yellow starthistle seedhead production was lower than the findings of Pitcairn (etal) (2000 average of 1.75-1.85 and 2001 average of 2.24-2.63). In addition, soil depth appeared to be a limiting factor. Therefore, intraspecific and interspecific plant competition caused by varying soil depth and plant density, may be effecting seedhead production.

Early - seral stages had the deepest soil, followed by mid - seral stages, and late - seral stages having the shallowest soil. At early seral stages, where soil depth is greatest, field inspections found that yellow starthistle densities are highest. Yellow starthistle is able to take advantage of the deeper soil and fully develop its root system. However, these high densities can cause intraspecific competition for soil resources, resulting in reduced numbers of seedheads per plant.

At mid- and late - seral stages, soil depth is shallower, perhaps reducing yellow starthistle's ability to fully develop its taproots, thus reducing densities. As a result, yellow starthistle plants must compete for resources in the shallower soils with other plants that are more adapted to a shallow soil. In these seral stages perhaps a combination of interspecific and intraspecific competition causes not only a reduction in yellow starthistle densities, but also its ability to access soil nutrients and moisture in order to produce seedheads.

Greenhouse study

Germination trials

With the application of N there can be a significant effect on the seed germination of yellow starthistle. High levels of N input appear to inhibit yellow starthistle seeds and can suppress germination. There was a significant increase in germination at low levels of N across moisture treatments. Differences between 30% moisture/high N when compared to 20%, 10%, and 5% moisture/high may have been caused by leaching of N down to a lower section of the soil in the pot, removing the inhibiting effect at the surface, or by an interaction of moisture and N allowing for yellow starthistle seeds to germinate.

Seedhead trial

Since there was no significant difference in yellow starthistle seedhead production at the various soil fertility levels at the 5% and 10% treatments, it was concluded that yellow starthistle needs a higher amount of moisture to produce seedheads. There was a significant difference in seedhead production at the 30% and 20% soil moisture-high N/high P treatment levels when compared to 20% and 30% soil moisture-low N/low P treatment level. Therefore, the low soil fertility levels significantly reduced seedhead production. As a result, the data indicates an interaction between soil moisture and nutrients for yellow starthistle to produce seedheads.

Overall, when comparing 30% and 20% soil moisture-NhPh treatments to 10% and 5% soil moisture-NlPl, there was a significant reduction in seedhead production at the 10% & 5%-NlPl treatment level ($P \leq 0.0001$). Thus, if other plant species were able to reduce soil resource availability to yellow starthistle, matching the conditions created in this trial, yellow starthistle seedhead production could be reduced.

Recommendations for further studies

This study found that there was a negative response to germination of yellow starthistle with the application of nitrogen, particularly at high levels. A field study that evaluates yellow starthistle's ability to germinate with varying N levels in conjunction with other vegetation, could be performed. Such a study could also test the response of native and non-native vegetation associated with yellow starthistle at various levels of nitrogen application.

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